MANUAL

LOAD SCREENING TOOL
AND
EFFLUENT STATISTICS TOOL

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EFFLUENT STATISTICS TOOL

Prepared for
Water Research Users Group
Alberta Environment

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FOREWORD

Alberta Environment supports the use of tools such as computer models to provide information on the impact of an activity on the environment. This manual supports two software programs designed to provide information on the impact of wastewater effluent releases on receiving waters. ~~The software is available through the Alberta Environment Information Centre.~~

Prasad Valupadas
Project Manager
Alberta Environment

The software is available for download at the following Internet address:

http://www3.gov.ab.ca/env/waste/indwwater/index.html

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1. INTRODUCTION

This manual describes the use of a package of two tools developed for Alberta Environment by Golder Associates Ltd.:

1. Load Screening Tool; and
2. Effluent Statistics Tool.

The tools have been developed in Microsoft Excel 2002 and are compatible with Excel 2000 but not necessarily with previous versions. The tools are intended to facilitate screening of effluents for compliance with surface water quality objectives and computation of water quality based effluent limits based on the characteristics of the effluent discharge and receiving water.

The Load Screening Tool has the following features:

- automated screening and limit derivation for Alberta (AENV 1999), U.S. EPA (U.S. EPA 2002), and CCME (CCME 1999) objectives for acute and chronic protection of aquatic life, human health carcinogenic and non-carcinogenic, as well as user-defined objectives, based on Alberta Environment's *Water Quality Based Effluents Limits Procedures Manual* (AENV 1995);
- optional inclusion of loadings from sources upstream of the source for which limits are calculated (Assessment Source);
- options for calculating mixing zone restrictions including fractional mixing, spatial mixing and End-of-Pipe (EOP);
- advanced approximations for inputs to the Fischer equations to represent effluent flow and initial mixing and to allow for specification of multi-port diffusers;
- a form-based case specification of river characteristics, effluent characteristics and screening methodology;
- convenient storage and retrieval of cases based on river characteristics, effluent characteristics and objectives; and
- graphical output of mixing zone concentrations.

The Effluent Statistics Tool calculates a number of statistics for effluent water quality data from raw input files. The tool includes the following features:

- optional calculation of statistics on a seasonal basis;
- comparison of output statistics to water quality guidelines;
- optional automatic outlier removal;
- several options for selection of coefficient of variation (CV) for calculation of the Statistical Effluent Maximum (SEM);
- statistics generation based on normal distribution, lognormal distribution, and delta-lognormal distribution; and
- selection of optimum statistical distribution for historical water quality data based on a goodness-of-fit test.

1.1 Water Quality Based Effluents Limits Procedures

The Effluent Statistics and the Load Screening tools can be used to implement water quality based effluent limit procedures, which were originally developed by the US Environmental Protection Agency, and have been adapted for regulating surface water discharges in Alberta. The Alberta procedures are detailed Alberta Environment's *Water Quality Based Effluents Limits Procedures Manual* (AENV 1995).

The Procedures Manual is a key reference for setting water quality based effluent limits. The Effluent Statistics and Load Screening tools automate these procedures. Users need to understand the procedures for setting effluent limits to be able to use the tools effectively. The Procedures Manual should be considered as a companion document to this manual. Water quality guidelines, the Statistical Effluent Maximum (SEM), and mixing zone restriction methods are key to development of water quality based limits and are described in the following sections.

1.2 Water Quality Guidelines

Water quality guidelines are used by both tools. Guidelines include:

- acute and chronic guidelines for the protection of aquatic Life (AENV 1999, CCME 1999, U.S. EPA 2002);
- human health carcinogenic and non-carcinogenic (U.S. EPA 2002);
- technology standards (AENV 1997); and
- alternative criteria for carbonaceous biological oxygen demand (CBOD) (10 mg/L) and fecal coliforms (200 counts/100 mL).

The fecal coliform guideline is the Alberta (AEP 1993) direct contact and irrigation water-use guideline.

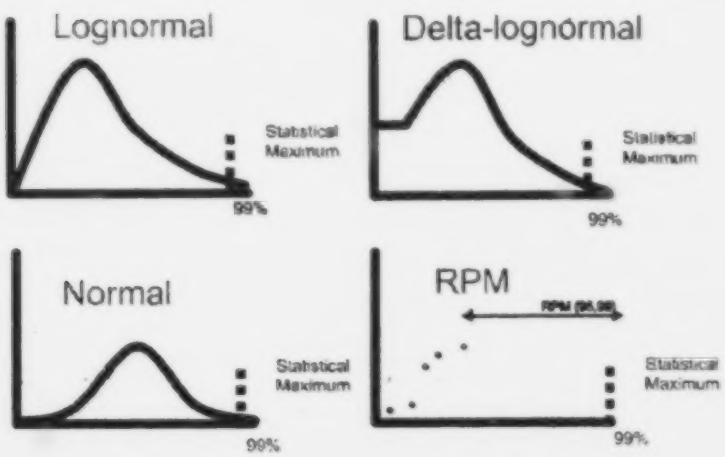
No specific guidelines for CBOD have been developed, but waters with levels greater than 10 mg/L are considered to be of concern since they contain large amounts of degradable organic material, which may lead to depressed dissolved oxygen concentrations (McNeely et al. 1979). This reference instream concentration may be used to assess CBOD, as the screening tool is not currently able to model dissolved oxygen. It is important to note that the modelling of CBOD should not be used as an indicator of potential impacts on in-stream dissolved oxygen.

1.3 Statistical Effluent Maximum (SEM)

Statistical distributions used to represent water quality data include normal, lognormal and delta-lognormal. These statistical distributions are not bounded on the upper end. Therefore, in order to determine if an effluent has a reasonable potential to exceed a water quality guideline, a "maximum" effluent concentration, called the SEM, must be specified. Typically the 99th percentile is taken as the SEM (Figure 1). When the sample size is less than 10, the SEM can be calculated using a reasonable potential multiplier (RPM). The RPM derives the 99th percentile of the expected lognormal distribution using a high confidence level (typically 95%) without fitting the data to a distribution.

When an assessment is being carried out with multiple upstream releases, using the 99th percentile for all releases may result in overly conservative estimates of instream concentrations.

Figure 1 Possible Distributions for Calculating the Statistical Effluent Maximum



1.4 Effluent Limits

A number of statistical values are associated with the development of effluent limits:

Wasteload Allocation (WLA) – The amount of a stream's total permissible substance load that is allocated to one or more existing or future point source releases. The total allowable substance load is determined by calculating the amount of substance that can be released while maintaining instream guidelines (AENV 1999). If the SEM is above the WLA then there is a "Reasonable Potential to Exceed" the water quality guideline.

Long Term Average (LTA) – The mean load or concentration of the substance in an effluent over the long term.

Maximum Daily Limit (MDL) – The absolute maximum allowable load or concentration of a substance that can be released by an individual source in one day. This value is typically represented by some upper percentile of existing or required performance.

Average Monthly Limit (AML) – The maximum averaged load or concentration of a substance that a facility may release into the receiving stream over some specified time period (i.e. one month). This value is typically represented by some upper percentile of existing or required performance. Details of determining the AML depend on the number of samples to be taken, and the degree of variability in the release.

1.5 Mixing Zone Restriction Methods

There are three options for calculating mixing zone restrictions and associated instream concentration: fractional mixing, spatial mixing and End-of-Pipe (EOP). More detailed information on the mixing zone algorithms used by the Load Screening Tool is presented in Appendix II.

Fractional mixing is a simple but widely used mixing zone approach, which assumes that the discharge is instantaneously mixed within the fraction of the flow specified. For example, if the worst-case scenario flow was set to 50 m^3/s and the flow fraction set to 10%, then the tool would assume a river flow of 5 m^3/s for the screening calculations. Using a flow fraction is generally considered to be conservative in terms of lateral mixing (i.e. the actual concentration will be less than or equal to the value calculated by the flow fraction approach), but it cannot reliably account for restrictions on the mixing zone. Likewise, it is difficult to account for upstream sources when using fractional mixing. The Load Screening Tool can assume either complete mixing or spatial mixing of upstream sources when fractional mixing of the Assessment Source is being used.

Spatial mixing calculates lateral (across the river), and longitudinal (down the river) gradients in substance concentrations away from the point of discharge, and screens the effluent based on the maximum concentrations at the lateral and longitudinal boundary of the mixing zone as set by the user. This option requires additional information about the river including the river width, velocity and lateral mixing coefficient (Appendix II).

End-of-Pipe requires the effluent to meet a certain limit based on technology or a water quality consideration. A water quality limit is based on a wasteload allocation to maintain instream guidelines. A technology limit is formulated on some statistical derivation of existing performance, or published sector-specific limits.

1.6 Overview of Tools

1.6.1 Effluent Statistics Tool

The effluent statistics tool can be used to identify optimal statistical distributions, remove outliers and calculate the SEM and other summary statistics. The tool is an Excel workbook. Raw data is entered into a separate workbook using a Raw Data Template. The location of input files and options for output generation are specified in the tool on the "User Input" sheet. Output tables are generated in a series of new files.

1.6.2 Load Screening Tool

The load screening tool contains 6 sheets that require model input data:

- Case – for saving data on individual input sheets and for loading previously saved data;
- WQ – for river and effluent chemistry information;
- Stats Calc Info – for specifying statistical characteristics of the effluent and of the limits to be calculated;
- Guidelines – there are default guidelines provided;
- Sources – for source flows, locations, and release characteristics; and
- MZ & River – for inputting river and mixing zone characteristics for each guideline type to be assessed.

The data for these sheets can be input manually or can be loaded from previously saved files using the buttons on the "Case" sheet. A sample scenario has been provided. The information is input by entering numbers in cells with white backgrounds as well as through drop-down boxes, check boxes and option buttons. Details for individual sheets are provided in Section 3.

Output is generated on the "Output" sheet. Several types of output can be generated using the following buttons:

- Update Table – updates a single substance output table on the "Output" sheet;

- Create Multi-Substance Output Table – Creates a detailed multi-substance output table on the "Output Table" sheet;
- Create Project Output – Creates a new workbook with all of the input and output information currently entered into the screening tool; and
- Create Contour Plot – Creates a contour plot in a new workbook, based on the information entered in the "Contour Information" table on the "Output" sheet.

2. EFFLUENT STATISTICS TOOL

The Effluent Statistics Tool is an Excel workbook that can be used to calculate a number of statistics for effluent water quality data from raw input files. Generated statistics are saved in an output file that is formatted for printing or data entry into the Load Screening Tool. Any of the following statistics can optionally be included in the output tables:

- Total Count: total number of observed data points (excluding outliers);
- Outlier Count: number of outliers of observed data points;
- Min (obs): minimum value of observed data points;
- Max (obs): maximum value of observed data points (excluding outliers);
- Median: median value of selected distribution;
- Mean: mean value of selected distribution;
- SD: standard deviation of selected distribution;
- CV: coefficient of variation of selected distribution;
- 99.91% ile: 99.91th percentile of selected distribution;
- R Squared: correlation coefficient squared as calculated from the regression of historical data and predicted values for selected distribution;
- ND Count: total count of values below the detection limit;
- ND Max: maximum value below the detection limit;
- ND Min: minimum value below the detection limit;
- Optimum Distribution: the statistical distribution that best fits historical WQ data;
- Acute Guideline Exceedance (%): the percentage of historical data that exceed the acute guideline; and
- Statistical Effluent Maximum (SEM): a threshold concentration that statistically can be exceeded by very low frequency (Section 1.3).

Appendix I provides flow charts for the process of outlier removal statistics generations, and optimal distribution selection for all distributions.

Raw data is entered into a separate workbook using a raw data template (Section 2.1). The location of input files and options for output generation are specified in the tool. Output tables

are generated in a new Excel file by clicking on the "Run" button. Calculations can be interrupted by pressing the escape key. A screen shot of the "User Input" sheet, where options are specified, is given in Figure 2.

Figure 2 Effluent Statistics Tool

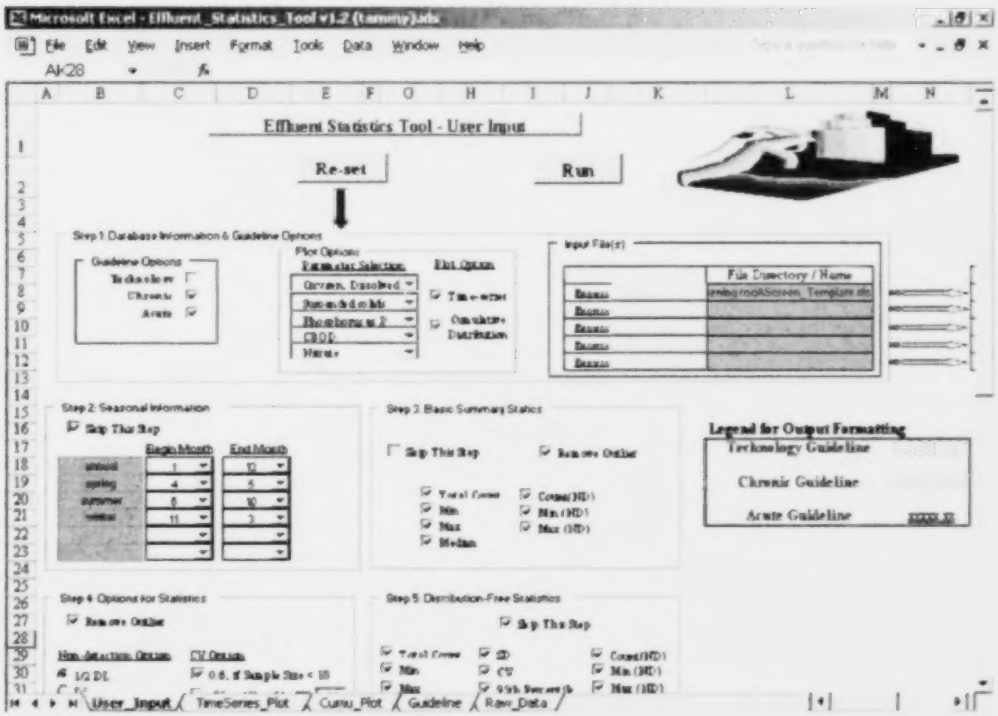


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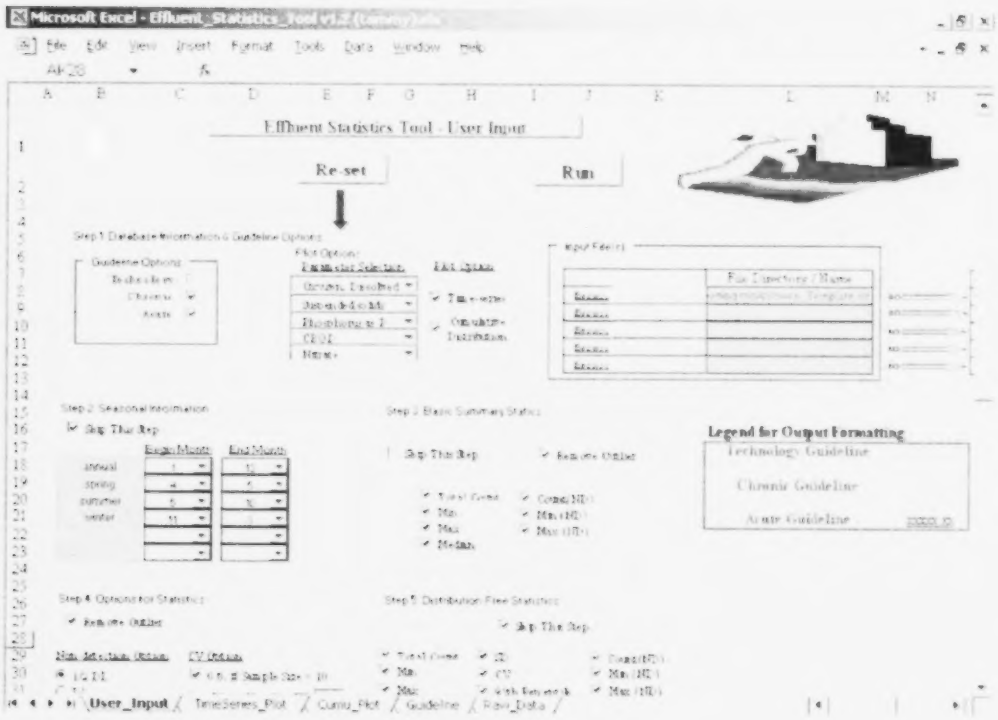
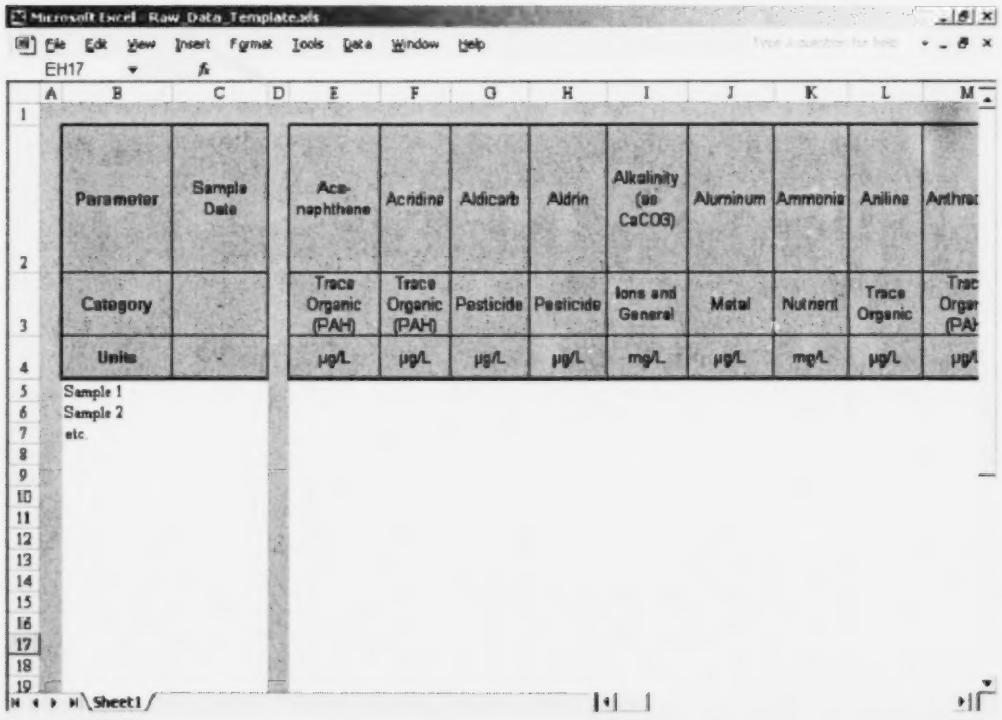
Figure 2 Effluent Statistics Tool



2.1 Input Format

A raw data template (Raw_Data_Template.xls; Figure 3) is provided with the Tool Package. Raw data must be entered into this template in order for the Effluent Statistics Tool to read the data properly. Raw data files can have up to ten sheets for different effluent data sets. Cells that have coloured backgrounds should not be modified. Enter water quality data in the appropriate column for each substance using the displayed units. If an observation is below the detection limit, enter a "<" followed by the detection limit value. A date must also be provided for each sample; however, if seasonal statistics are not required, the date can be arbitrary. Dates need not be sequential or start at any particular date.

Figure 3
Raw Data Template for the Effluent Statistics Tool

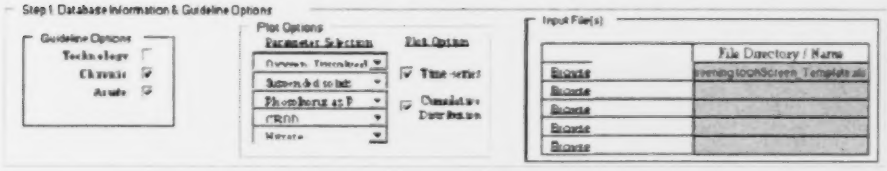


2.2 Setting Options for Output Production

Step 1: Database Information and Guideline Options

There are three input fields in this step (Figure 4). In the first step, select the guideline types that you would like the final effluent statistics to be compared to. Guideline comparisons will be displayed as a change in the formatting of the summary statistic values as shown in the legend on the "User_Input" sheet. In the second box, select up to five parameters to be graphed and select the type of graphs to be plotted. In the third box, use the browse buttons to select up to five data input files that have been created using the "Raw_Data_Template.xls" file to ensure proper formatting. To the right of the "Input File(s)" box, there is a table to list the name of each sheet in the data file.

Figure 4
Step 1: Database Information and Guideline Options



Step 2: Seasonal Information

This step allows for calculation of summary statistics for multiple seasons (Figure 5). Enter the name of the season in the green box (this will be used as a label) and select the beginning and ending months of the season using the drop-down boxes.

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A raw data template (Raw_Data_Template.xls; Figure 3) is provided with the Tool Package. Raw data must be entered into this template in order for the Effluent Statistics Tool to read the data properly. Raw data files can have up to ten sheets for different effluent data sets. Cells that have coloured backgrounds should not be modified. Enter water quality data in the appropriate column for each substance using the displayed units. If an observation is below the detection limit, enter a "<" followed by the detection limit value. A date must also be provided for each sample; however, if seasonal statistics are not required, the date can be arbitrary. Dates need not be sequential or start at any particular date.

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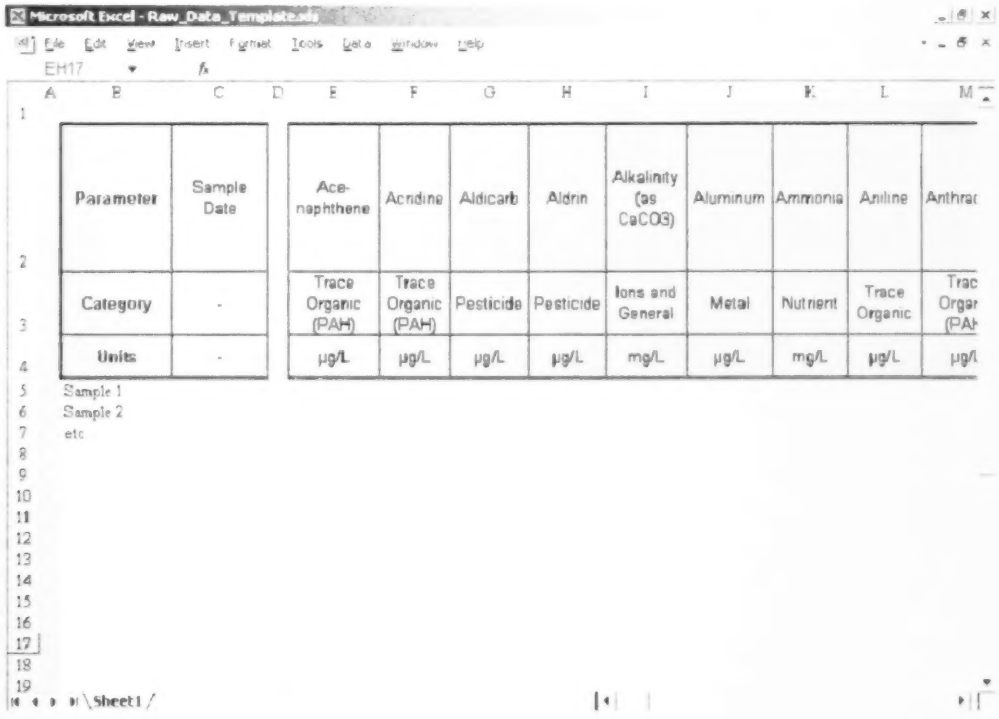

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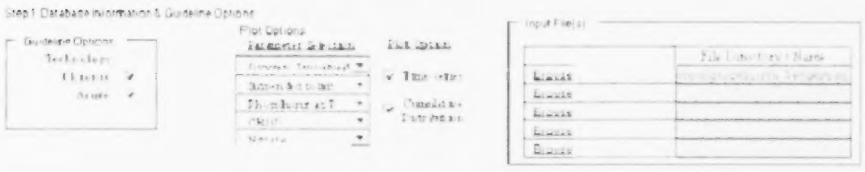

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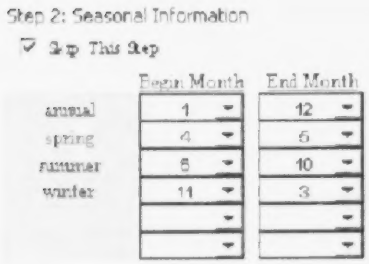
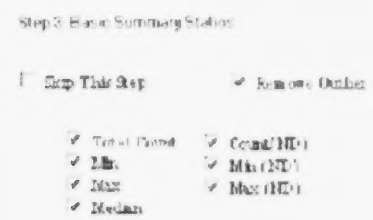


Step 3: Basic Summary Statistics

This step will create a table with basic summary statistics which conserve information on non-detect values in the input data set (Figure 6). Use the check boxes to select the types of summary statistics to be generated in the output table. Outliers will be removed if the "Remove Outlier" check box is selected. If this information is not required the step can be skipped by selecting the "Skip This Step" check box.

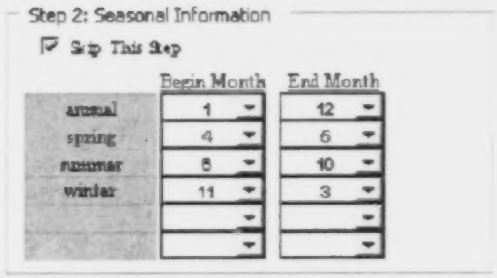
Figure 6
Step 3: Basic Summary Statistics



Step 4: Options for Statistics

This step allows for specification of some of the options for the following steps, which provide additional statistics (Figure 7). In the following steps, statistics are calculated based on four possible distribution options: distribution-free, normal, lognormal, and delta-lognormal. The following steps can be done with or without outlier removal by selecting the "Remove Outlier" check box. The outlier removal method is provided in Appendix I.

Figure 5
Step 2: Seasonal Information



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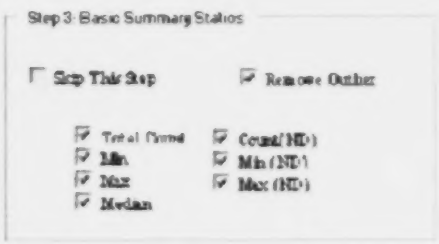

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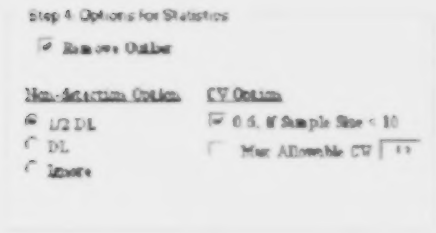
Figure 7
Step 4: Options for Statistics



For all but the delta-lognormal distribution (Step 8), non-detect observations need to be modified in order to calculate summary statistics. Options for modifying non-detect values include replacing them by half the detection limit, replacing them by the detection limit or ignoring them all together.

The coefficient of variation (CV) is required for the calculation of the SEM. The Procedures manual recommends that a CV of 0.6 be used unless an alternative CV can be confidently calculated. There is a check box to use a CV of 0.6 if sample sizes are less than 10. There is also a check box and input box to allow for specification of a maximum allowable CV. If neither of these boxes are checked then the calculated CV will be always be used to calculate the SEM.

Steps 5 – 8, Statistics Output Options

Percentiles can be calculated based on a number of statistical distributions or based simply on the observed data. In each of steps 5 though 8, tables are produced that optionally can contain summary statistics and percentiles (Figures 8 to 11). For each step, select "Skip this Step" if a table based on the relevant distribution is not required. Select the summary statistics that are to be included in the output file for each step if the step is not skipped. Check the appropriate box for the 95th and/or 99th percentiles for calculation of the SEM. If calculation of the SEM using RPM is being used, then the confidence level required must be entered in the box provided. Refer to the Procedures Manual for further discussion of the SEM, RPMs and the relevant percentiles.

Figure 8
Step 5: Distribution-Free Statistics

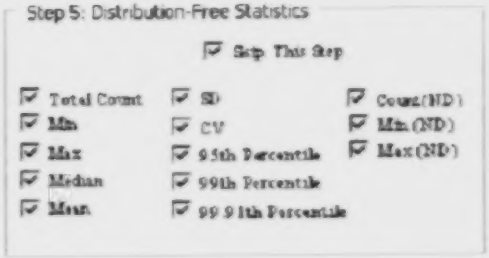


Figure 9
Step 6: Normal Distribution Statistics

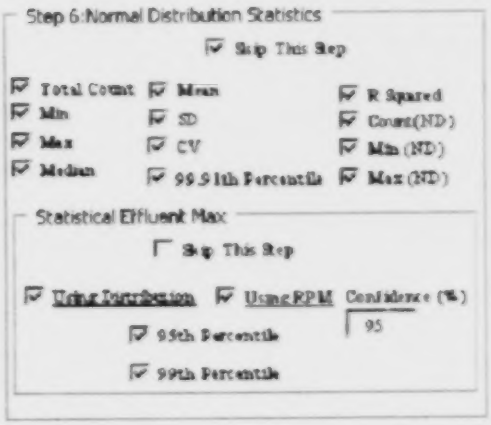


Figure 10
Step 7: Lognormal Distribution Statistics

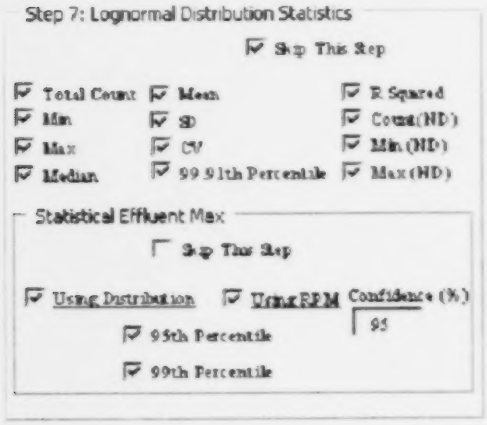
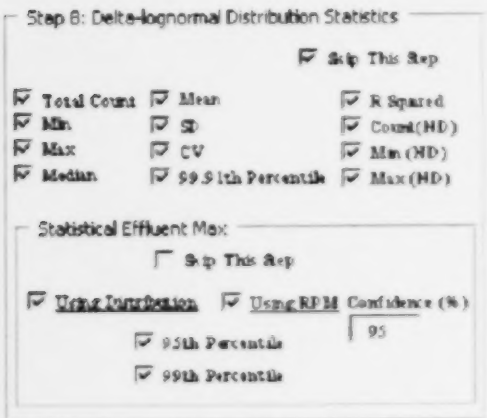


Figure 11
Step 8: Delta-lognormal Distribution Statistics

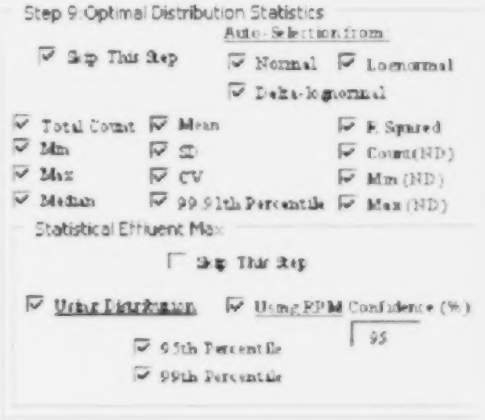


Step 9: Optimal Distribution Statistics

The final type of table that can be produced includes selection of the best-fit statistical distribution for each parameter from among selected distributions (Figure 11). The effluent statistics tool processes for distributions is described in Appendix I. The SEM can be calculated based on the distribution or using the RPM. The output for this step will also include a single column that provides the best SEM for each parameter based on all of the distributions, and if the

sample size is less than 10, using RPM. Typically, this will be the column that is used as input water quality for the Load Screening Tool.

Figure 12
Step 9: Optimal Distribution Statistics



2.3 Guidelines Sheet

The "Guidelines" sheet is identical to the one used in the Load Screening Tool (Section 3.1.6), with the exception of the location for entering background water quality for calculation of guidelines. The Effluent Statistics Tool allows for seasonal guideline calculations so several values for each parameter may be required. Figure 13 shows the input table for seasonal water quality statistics used to calculate guidelines.

Figure 13
Receiving Waterbody Water Quality for Seasonal Guideline Calculations

		Seasons					
Parameter	Units	annual	spring	summer	winter		
pH	-	8	8	8.2	7.8		
temp	oC	4.97	5.97	17.04	0.055		
hardness	mg/L	167	154	161	180		
TSS	mg/L	1615	1602	1368	26		
Selenite/Selenate fractions, f1/f2	-						

sample size is less than 10, using RPM. Typically, this will be the column that is used as input water quality for the Load Screening Tool.

Figure 12
Step 9: Optimal Distribution Statistics

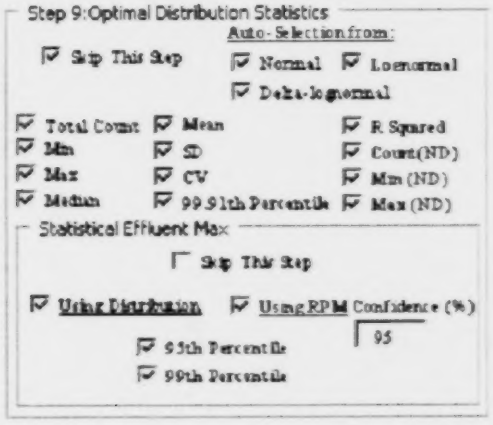


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Figure 13
Receiving Waterbody Water Quality for Seasonal Guideline Calculations

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		annual	spring	summer	winter		
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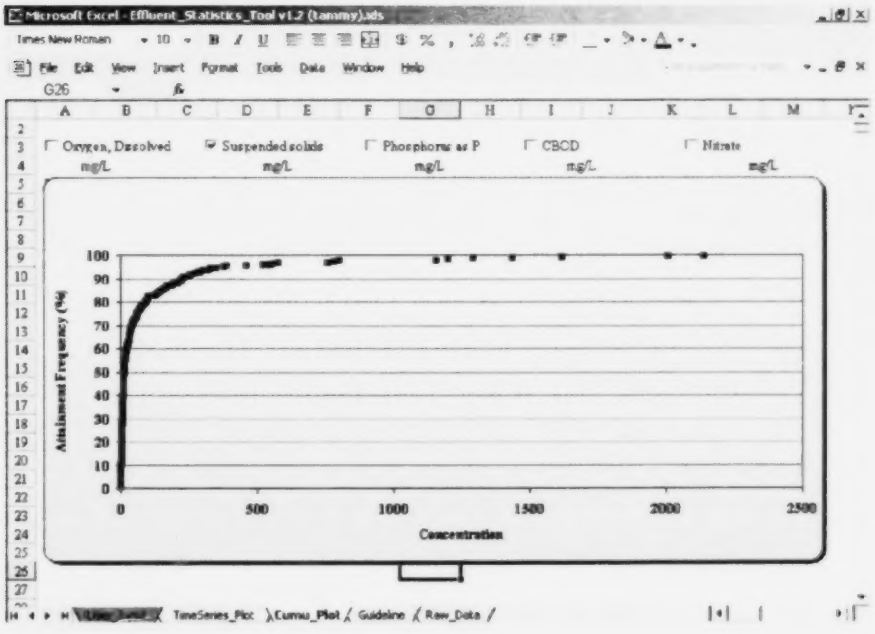
hardness	mg/L	167	154	161	180		
TSS	mg/L	1615	1602	1368	26		
Selenite/Selenate fractions, f1/f2	-						

2.4 Output

Graphical Output

Graphical output can be created for up to five substances. Graphical output is created for the first sheet of the first file of a group of input data sheets (Step 1). The graphical output is contained within the effluent screening tool and is temporary unless the graphs are manually transferred to another document. A sample output graph is shown in Figure 14.

Figure 14
Output Graph for the Effluent Statistics Tool



Tabular Output

For each of steps 3, and 5 - 9, a new output file is created for each of the input files. The first part of the output file name describes the step that the output corresponds to. The second part of the output file name is the original input file name. For example, if an input file (raw data file) was named "test.xls" then the output files would be "Normal_test.xls", "Optimal_test.xls", etc. Sample output files are included with the Tool Package.

3. LOAD SCREENING TOOL

The Load Screening Tool contains 6 sheets that require model input data. There are two sheets that produce model output and several types of output files can be generated.

3.1 User Input

3.1.1 Conventions

Input boxes (standard excel cells) have white background for numeric input, grey background for text input, or have coloured hatch if not in use. The following are important features of input boxes:

- Presence of cross-hatch may change when check boxes and drop-down boxes are changed.
- Before producing output, all input boxes without cross hatch must have values entered. Failure to ensure that appropriate numeric values are placed in all input boxes will result in erroneous model output or tool malfunction.

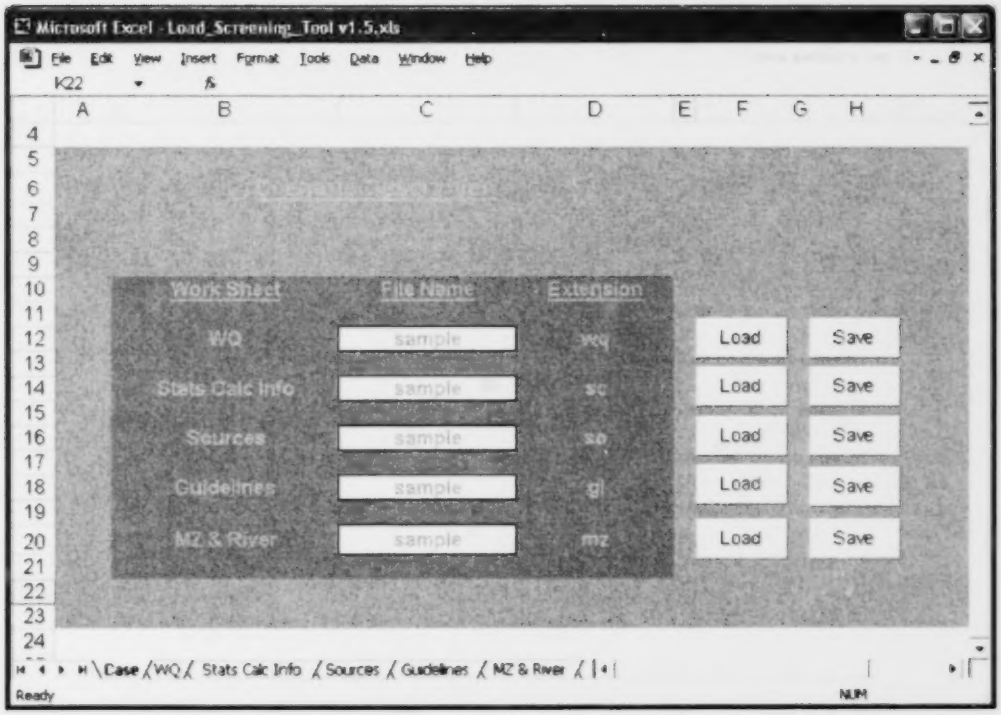
Typically, drop-down boxes must have an option selected for proper functioning of the tool. Check boxes and option buttons are used to select from a number of calculation options. Selected options will affect calculations and the required input data and therefore will change the crosshatching of various input cells.

Buttons are used to produce various outputs (Section 3.2) as well as to load and save input data (Section 3.1.2).

3.1.2 Case Sheet

The Load Screening Tool input data can be saved for each sheet using the input cells (grey background) and the "Save" button (Figure 15). Type the name that you want to save the data file as, then click the "Save" button. To load a previously saved input page, click on the "Load" button and browse for the desired file.

Figure 15
Case Sheet

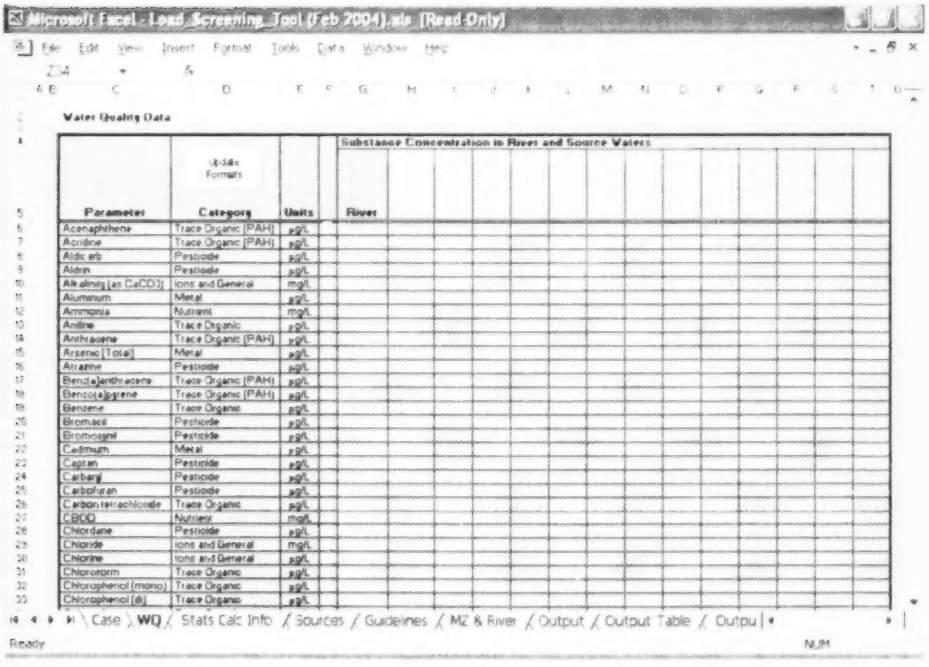


3.1.3 WQ Sheet (Water Quality Sheet)

The "Water Quality" sheet (Figure 16) allows for input of water quality information used by the tool. The Effluent Statistics Tool can be used to produce data for this page. Data is entered on this page as follows:

- Click the check box for each parameter that will be included in the analysis.
- Click on the "Update Format" button and the unused rows will become hatched.
- Enter the river water quality concentrations for upstream boundary of the reach being considered.
- Enter a title (grey background) and water quality concentrations (white background) for each unique water that will be included in the analysis (note that individual releases need not have unique water quality). Typically, the SEM is used to represent effluent concentrations, however, in some cases alternate values may be used (AENV 1999).

Figure 16
WQ Sheet (Water Quality Sheet)


Microsoft Excel - Load_Screening_Tool (Feb 2004).xls [Read-Only]
File Edit View Insert Format Tools Data Window Help
Water Quality Data
Update Formats
Substance Concentration in River and Source Waters
Parameter
Category
Units
River
Acenaphthene Trace Organic (PAH) µg/L
Acridine Trace Organic (PAH) µg/L
Aldrin Pesticide µg/L
Alkalinity (as CaCO3) Ions and General mg/L
Aluminum Metal µg/L
Ammonia Nutrient mg/L
Aniline Trace Organic µg/L
Anthracene Trace Organic (PAH) µg/L
Arsenic (Total) Metal µg/L
Atrazine Pesticide µg/L
Benz[a]anthracene Trace Organic (PAH) µg/L
Benzo(a)pyrene Trace Organic (PAH) µg/L
Benzene Trace Organic µg/L
Bromacil Pesticide µg/L
Bromoxynil Pesticide µg/L
Cadmium Metal µg/L
Captan Pesticide µg/L
Carbaryl Pesticide µg/L
Carbofuran Pesticide µg/L
Carbon tetrachloride Trace Organic µg/L
CBOD Nutrient mg/L
Chlordane Pesticide µg/L
Chloride Ions and General mg/L
Chlorine Ions and General µg/L
Chloroform Trace Organic µg/L
Chlorophenol (mono) Trace Organic µg/L
Chlorophenol (di) Trace Organic µg/L
Case WQ Stats Calc Info Sources Guidelines MZ & River Output Output Table Outpu
Ready
NUM

3.1.3 WQ Sheet (Water Quality Sheet)

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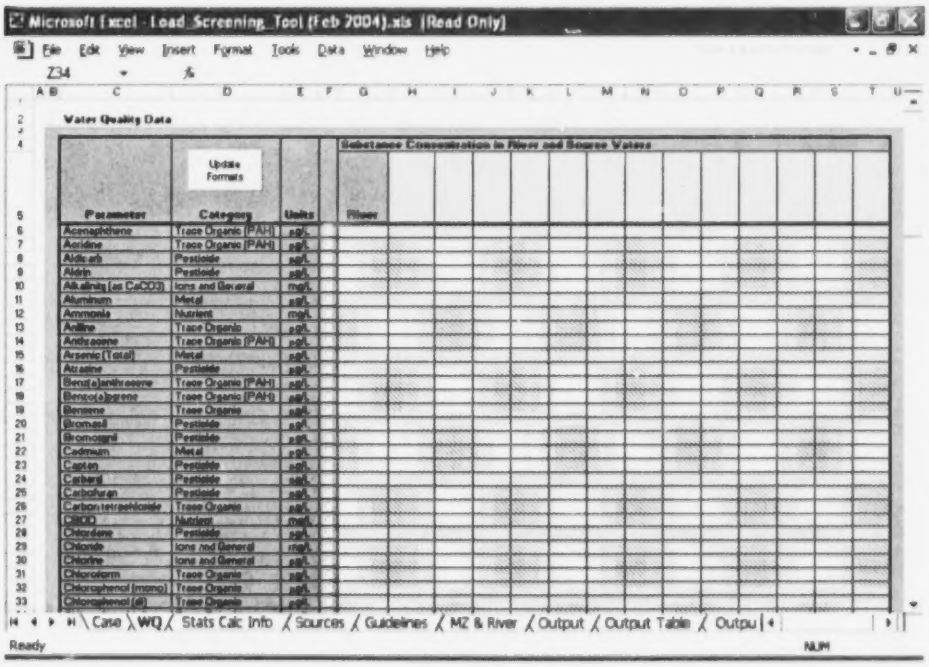
Figure 16
WQ Sheet (Water Quality Sheet)



3.1.4 Stats Info Sheet (Statistics Calculation Information Sheet)

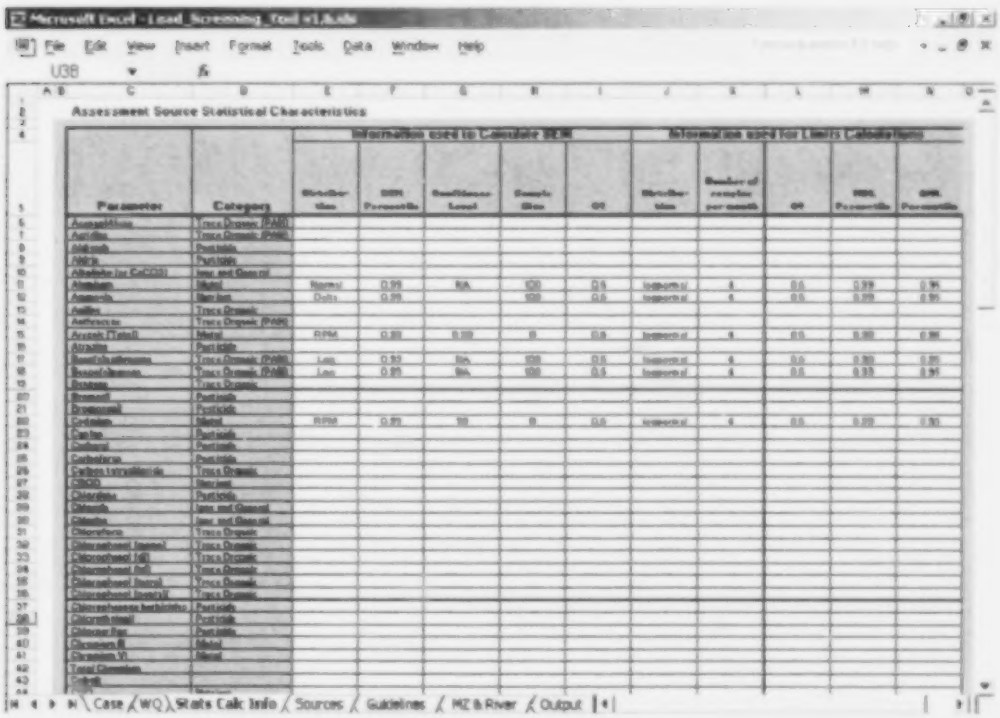
This sheet (Figure 17) contains a record of the information that was used to calculate the SEM for the effluent and information that will be used by the Load Screening Tool to calculate effluent limits. The first section of data is simply a record and is optional:

- **Distribution** (optional) – the distribution that was used to calculate the SEM for the effluent. Possible values include: normal, lognormal, delta-lognormal and RPM;
- **SEM Percentile** (optional) – the percentile that was used to calculate the SEM (i.e., the number of data points that will be less than or equal to the calculated SEM based on the distribution chosen);
- **Confidence Level** (optional) – The confidence level that was used to calculate the SEM if an RPM was used;
- **Sample Size** (optional) – number of data points in the recorded effluent concentration data set; and
- **CV** (optional) – effluent coefficient of variation that was used to calculate the SEM.

The following information is required to calculate effluent limits:

- **Distribution** – The distribution used to calculate limits can be either lognormal or normal;
- **Samples per Month** – the number of samples collected per month for determining effluent limits (usually set to 4);
- **CV** – effluent coefficient of variation used to calculate limits;
- **MDL Percentile** – Probability that the actual allowable MDL will be greater than or equal to the calculated MDL; and
- **AML Percentile** – Probability that the actual allowable AML will be greater than or equal to the calculated AML.

Figure 17
Stats Info Sheet (Statistics Calculation Information Sheet)



3.1.5 Sources Sheet

The "Sources" sheet (Figure 18) contains information on the attributes of the Assessment Source and sources upstream of the Assessment Source. Data is entered on this page as follows:

- In the "Name" column, enter the name of each of the sources including the Assessment Source and any upstream sources.
- In the "Concentration Description" column, use the drop-down box to select the water type that corresponds to the source.
- In the "Flow" column, enter the flow corresponding to each source (typically the average flow) including the Assessment Source.

- In the "Longitudinal Location" column, enter the distance downstream of a reference point for each of the sources. Note that the location of the reference point is not important, as long as it is upstream of all sources.
- In the "Lateral Location" column, enter the lateral location of the source, relative to the left bank facing downstream, as a fraction of the total width of the river. For example, facing downstream, discharges on the left bank, centre, and right bank would have lateral locations of 0.0, 0.5, and 1.0 respectively.
- In the "Type" column, use the drop-down box to select the source type. "Point" corresponds to a simple pipe, "line" corresponds to a multi-port diffuser, and "exp line" corresponds to a seepage.
- In the "Source Width" column, specify the width (in meters) of the source for multi-port diffusers and seepages.

Figure 18
Sources Sheet

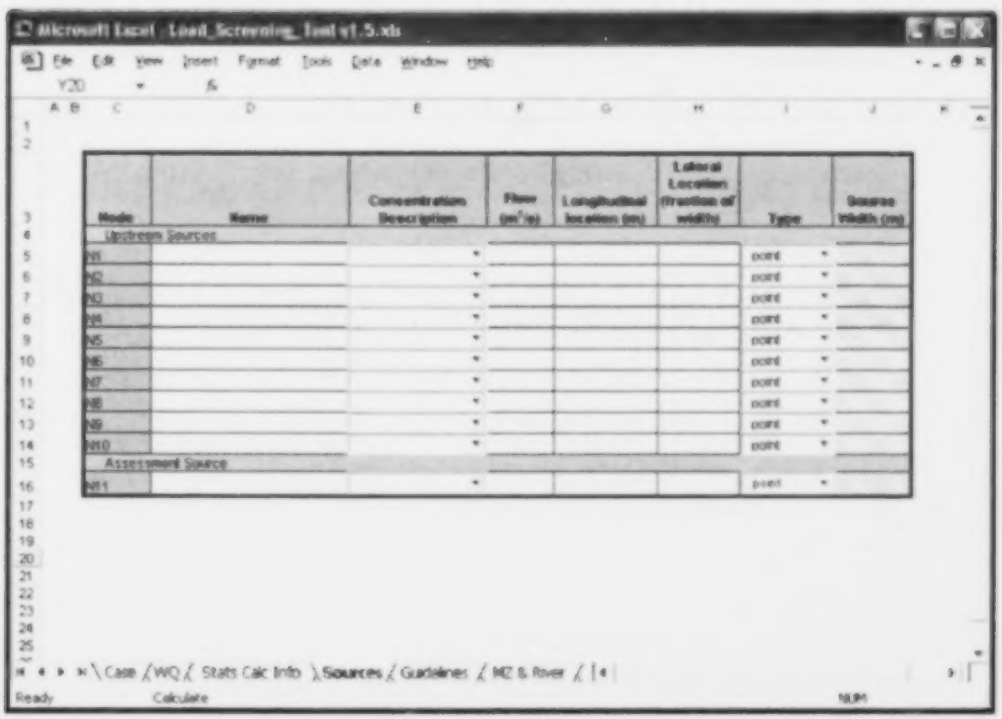


Figure 17
Stats Info Sheet (Statistics Calculation Information Sheet)

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- In the "Longitudinal Location" column, enter the distance downstream of a reference point for each of the sources. Note that the location of the reference point is not important, as long as it is upstream of all sources.
- In the "Lateral Location" column, enter the lateral location of the source, relative to the left bank facing downstream, as a fraction of the total width of the river. For example, facing downstream, discharges on the left bank, centre, and right bank would have lateral locations of 0.0, 0.5, and 1.0 respectively.
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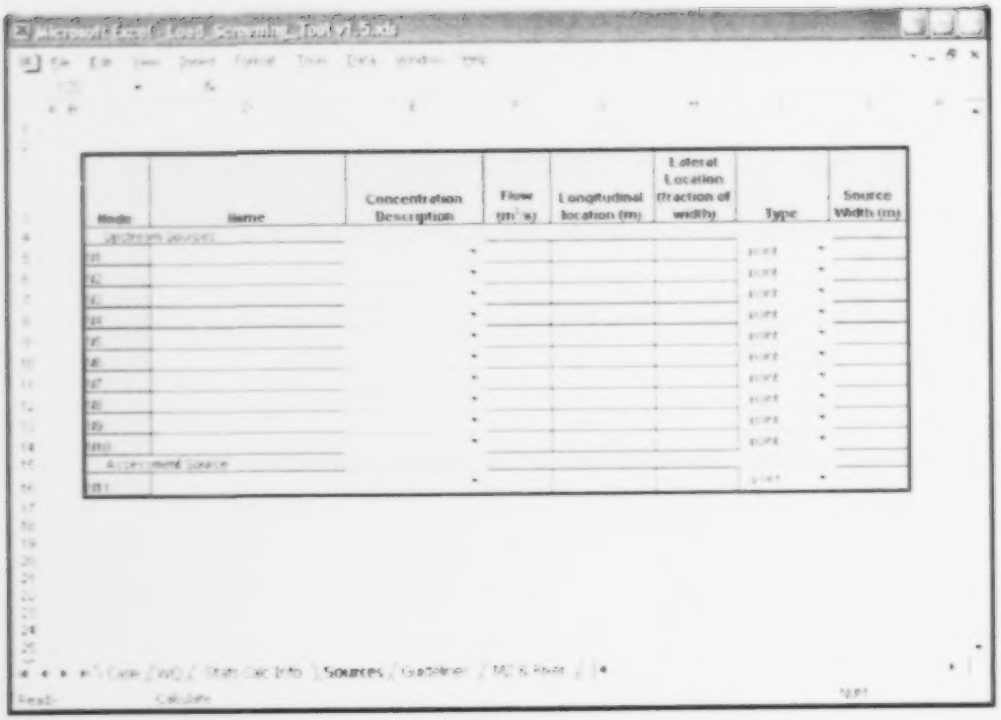
Figure 18
Sources Sheet

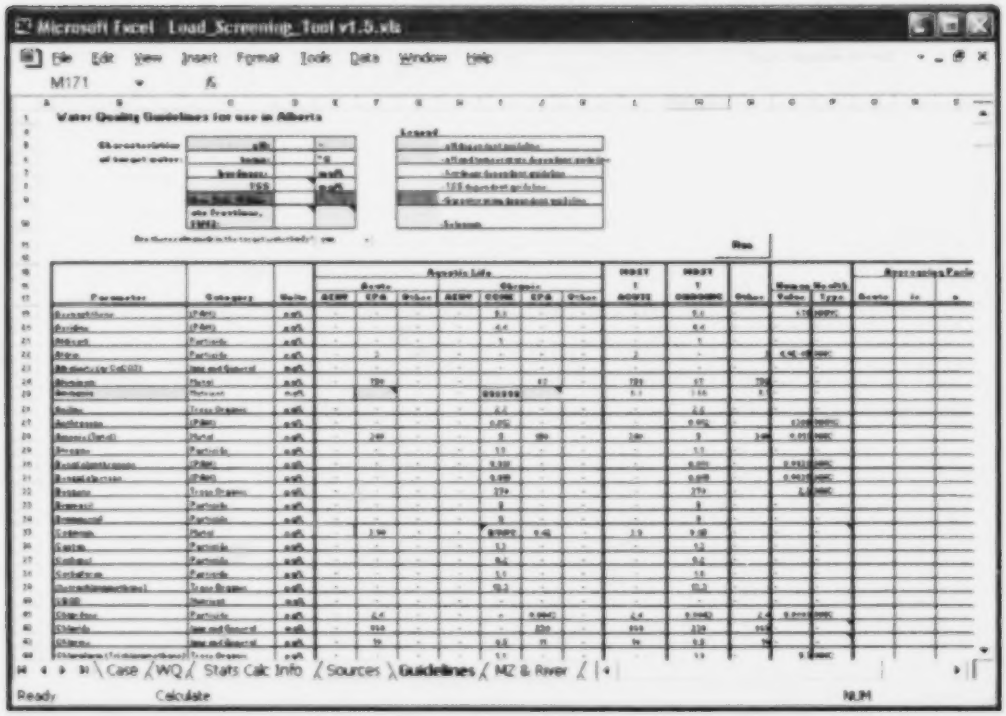


3.1.6 Guidelines Sheet

Guidelines for parameters such as ammonia, cadmium, chromium, copper, lead, nickel, silver and zinc are dependant on the temperature, pH and/or hardness of the waterbody, and are colour-coded to indicate necessary input for the guideline calculation. Data is entered on this page (Figure 19) as follows:

- Enter characteristics of the target waterbody such as pH, temperature, and hardness. If none of the substances being screened are dependent on a given parameter, then a value is not required.
- Customize water quality guidelines where appropriate. Individual guidelines may be edited if there is a justification for the target water body or case under consideration. If guidelines are deleted, they must be replaced by dashes.
- Click on the "Run" button to update the list of most stringent guidelines. This must be done, as guidelines change based on characteristics of the target waterbody.

Figure 19
Guidelines Sheet



3.1.7 MZ &River Sheet (Mixing Zone and River Sheet)

This page (Figure 20) characterizes the river and assessment characteristics used to assess each guideline type. Data is entered into the two tables on this page as follows:

- In the first row of the first table ("MZ Restriction Method"), use the drop-down boxes to select the mixing zone restriction method for each guideline type (i.e., Acute, Chronic, HHC, HHNC, and Other). Options include: fractional mixing, spatial mixing, end-of-pipe or alternatively the guideline type can be excluded from consideration in calculating effluent limits. Selection of the mixing zone restriction method will create hatching in cells that are not required for that type of calculation.
- Fill in appropriate numerical values for the non-hatched cells in the two tables:
  - "Fraction" refers to the fraction of river flow to be used for fractional mixing calculations.
  - "Zone Width" is the width of the mixing zone in meters and is used for spatial mixing calculations.
  - "Zone Length" is the length of the mixing zone in meters and is used for spatial mixing calculations.
  - "Flow" is the river flow that is appropriate for the guideline type and is used for spatial and fractional mixing calculations.
  - "Average Width" is the average width of the river in meters and is used for spatial mixing zone calculations and fractional mixing zone calculations when there are upstream sources.
  - "Average Velocity" is the average velocity of the river corresponding to the chosen flow and is used for spatial calculations and for fractional mixing zone calculations when there are upstream sources.

Below the two input tables is additional information for the mixing characteristics of the river. There are 2 options for mixing coefficient specification:

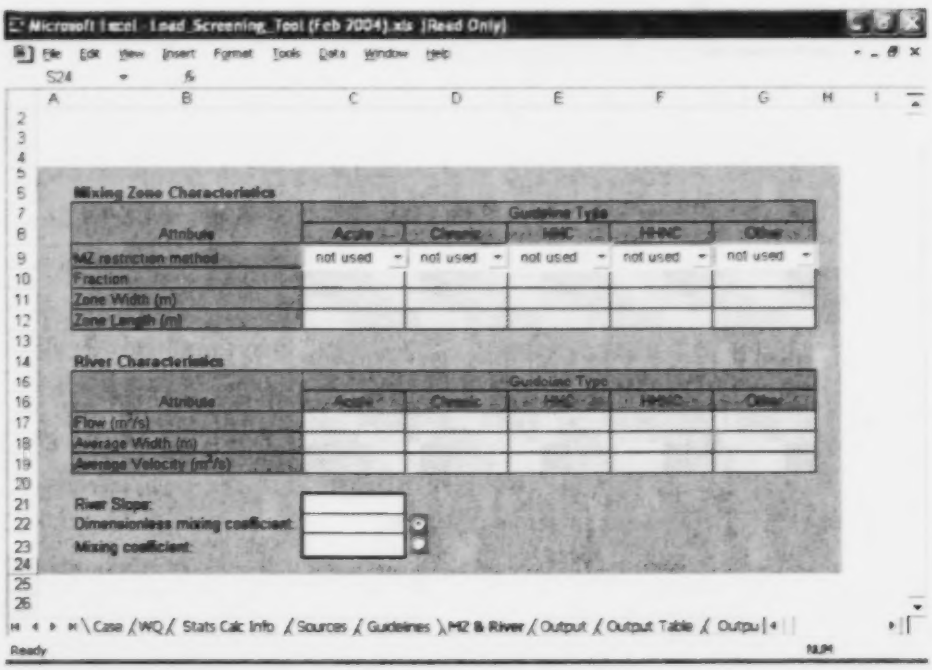
- Specify dimensionless mixing coefficient: if the option button beside "Dimensionless mixing coefficient" entered is selected then both a dimensionless mixing coefficient and a slope need to be entered.

- Specify a mixing coefficient: if the option button beside "Mixing Coefficient" is selected, then only the mixing coefficient needs to be specified.

The dimensionless mixing coefficient is a unitless coefficient which is based on the mixing characteristics of the river. The dimensionless mixing coefficient ranges from 0.4 to 0.8 for most natural streams, with a typical value of 0.6. The mixing coefficient will be lower for streams with relatively straight, uniform channels and higher for streams with sharp curves or rapid changes in geometry. A value of 0.6 is recommended for most streams.

When a fractional mixing zone restriction is used, values for spatial mixing calculations may still be required in order to estimate contributions from upstream sources. In this case, the results should not be very sensitive to the river characteristics entered. For example, a rough estimate of the width and velocity of the river along with an estimate of the slope from Appendix III and a dimensionless mixing coefficient of 0.6 should be adequate to estimate upstream concentrations for fraction of flow calculations.

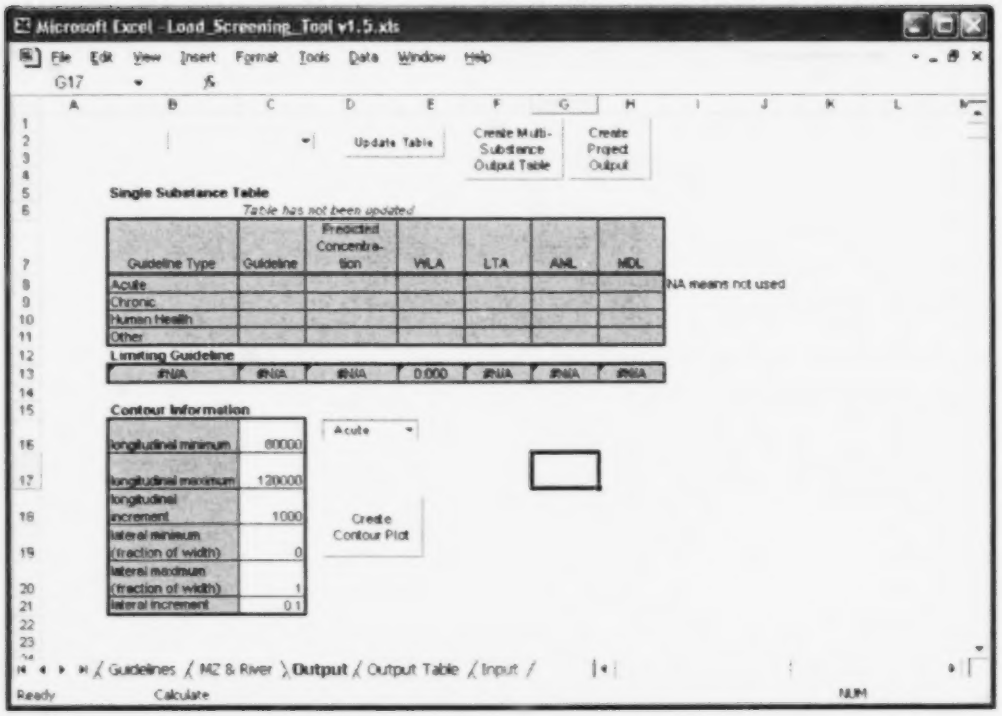
Figure 20
MZ & River Sheet (Mixing Zone and River Sheet)



3.2 Output

All output is generated from the "Output" sheet (Figure 21).

Figure 21
Output Sheet (Output Options Sheet)



Single Substance Output Table

This table gives a preview of effluent limits for a single substance. To update this table, select a substance using the dropdown box and then click the "Update Table" button. Limits for each guideline type are given as well as the guideline and the predicted concentration based on the mixing zone restriction method selected for each substance. If the predicted concentration is higher than the guideline, then there is a reasonable potential to exceed the water quality guideline. Similarly if the SEM is higher than the WLA then there is a reasonable potential to exceed the water quality guideline. The guideline with the lowest WLA is the limiting guideline.

- Specify a mixing coefficient: if the option button beside "Mixing Coefficient" is selected, then only the mixing coefficient needs to be specified.

The dimensionless mixing coefficient is a unitless coefficient which is based on the mixing characteristics of the river. The dimensionless mixing coefficient ranges from 0.4 to 0.8 for most natural streams, with a typical value of 0.6. The mixing coefficient will be lower for streams with relatively straight, uniform channels and higher for streams with sharp curves or rapid changes in geometry. A value of 0.6 is recommended for most streams.

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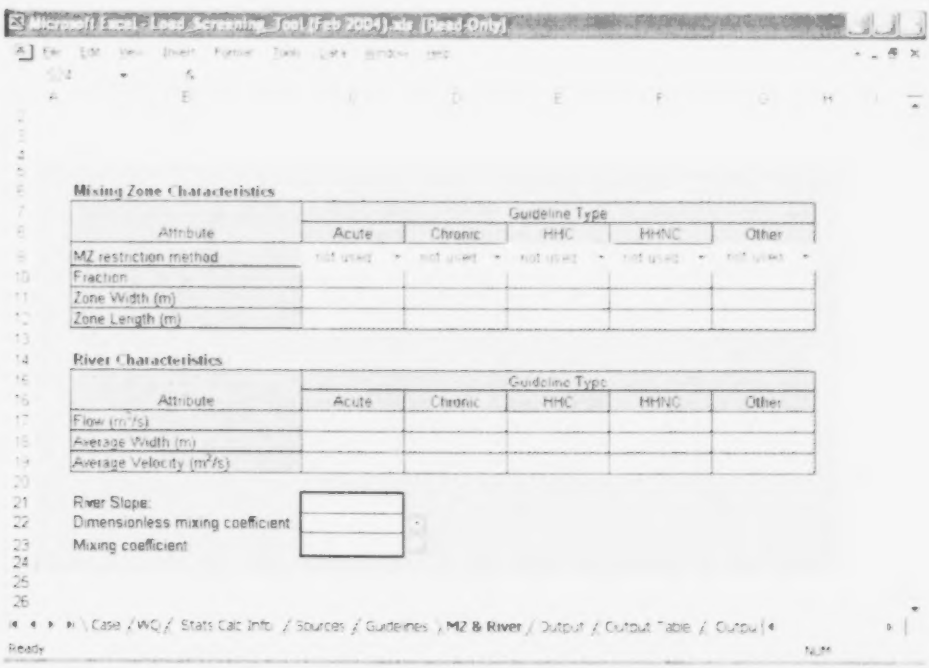
Figure 20
MZ & River Sheet (Mixing Zone and River Sheet)



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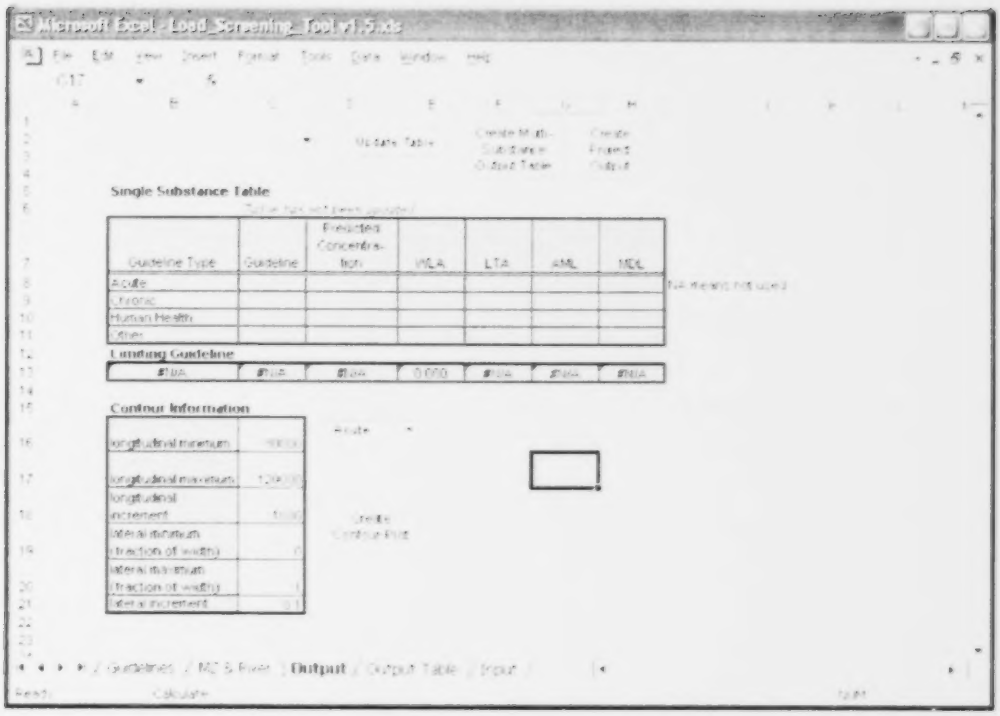
All output is generated from the "Output" sheet (Figure 21).

Figure 21
Output Sheet (Output Options Sheet)



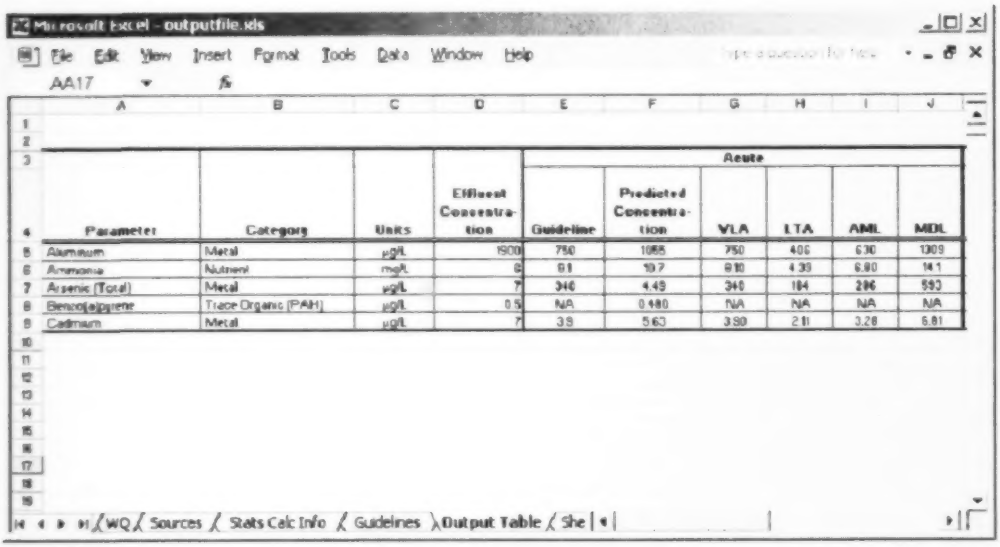
Single Substance Output Table

This table gives a preview of effluent limits for a single substance. To update this table, select a substance using the dropdown box and then click the "Update Table" button. Limits for each guideline type are given as well as the guideline and the predicted concentration based on the mixing zone restriction method selected for each substance. If the predicted concentration is higher than the guideline, then there is a reasonable potential to exceed the water quality guideline. Similarly if the SEM is higher than the WLA then there is a reasonable potential to exceed the water quality guideline. The guideline with the lowest WLA is the limiting guideline.

Multi-Substance Output Table

To create this table, click on the "Create Multi-substance Output Table" button. The table is created on the "Output Table" sheet and includes all of the information on the single substance output table, but includes all of the substances that are being assessed (Figure 22). Descriptions of the effluent limits reported in the table are given in Section 1.4.

Figure 22
Output Tables Sheet


Microsoft Excel - outputfile.xls
File Edit View Insert Format Tools Data Window Help
AA17
Acute
Parameter
Category
Units
Effluent Concentration
Guideline
Predicted Concentration
WLA
LTA
AML
MDL
Aluminum Metal µg/L 1500 750 1065 750 406 630 1309
Ammonia Nutrient mg/L 8 9.1 19.7 9.10 4.39 6.80 14.1
Arsenic (Total) Metal µg/L 7 340 4.49 340 184 286 593
Benco[a]pyrene Trace Organic (PAH) µg/L 0.5 NA 0.480 NA NA NA NA
Cadmium Metal µg/L 7 3.9 5.63 3.90 2.11 3.28 6.81
WQ Sources Stats Calc Info Guidelines Output Table She

Contour Plot

To create a contour plot, fill in the information in the "Contour Information" table, select the relevant substance and guideline type using the drop-down boxes, and then click the "Create Contour Plot" button. The "Contour Information" table specifies the spatial extent and resolution of the contour plot (Figure 23). The longitudinal minimum and maximum are relative to the upstream reference point, and are the upper and lower bounds of the contour plot respectively. The lateral minimum and maximum are the left and right bounds of the contour plot respectively. The lateral and longitudinal increments specify the frequency that instream concentrations are calculated, and therefore the resolution of the contour plot. Figure 24 shows a sample contour plot.

Figure 23
Contour Information Table

Contour Information

longitudinal minimum (m)	80000
longitudinal maximum (m)	120000
longitudinal increment (m)	1000
lateral minimum (fraction of width)	0
lateral maximum (fraction of width)	1
lateral increment (fraction of width)	0.1

Acute

Create Contour Plot

Figure 24
Example Contour Plot

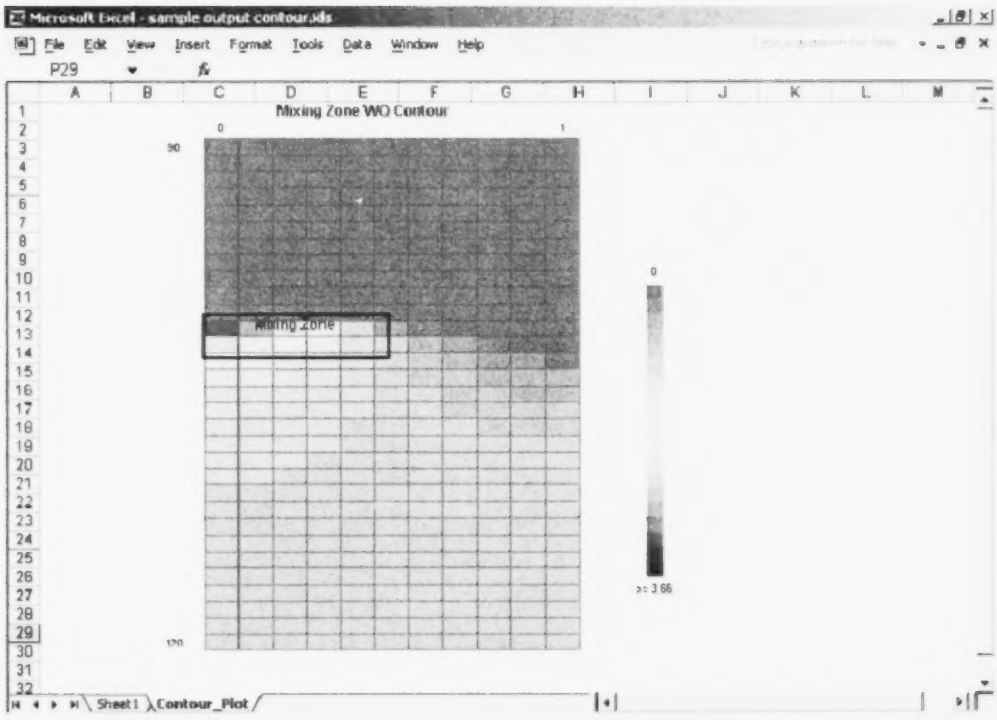

Microsoft Excel - sample output contour.xls
File Edit View Insert Format Tools Data Window Help
P29
Mixing Zone WO Contour
Mixing Zone
Sheet1 Contour_Plot

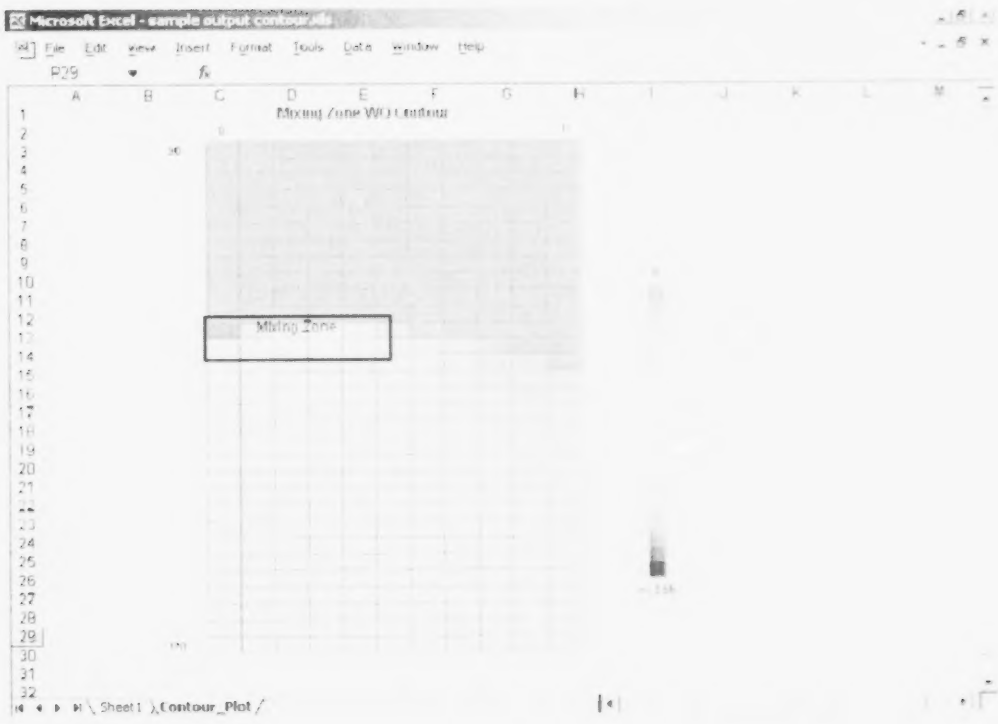
Figure 23
Contour Information Table

Contour Information

longitudinal minimum (m)	80000
longitudinal maximum (m)	120000
longitudinal increment (m)	1000
lateral minimum (fraction of width)	0
lateral maximum (fraction of width)	1
lateral increment (fraction of width)	0.1

Create Contour Plot

Figure 24
Example Contour Plot


Microsoft Excel - sample output contour.xls
File Edit View Insert Format Tools Data Window Help
P29
Mixing Zone WQ Contour
Mixing Zone
Sheet1 Contour_Plot

Project Output

To create project output, click on the "Create Project Output" button. The multi-substance output table must be created first (even if you are only analyzing a single substance) so that the output table will be included in the Project Output file. A sample project output file is included in the Tool Package. The purpose of this output is to keep a record of all of the input information that was used to create the multi-substance output table and to calculate limits. The output is essentially a copy of all the input and output sheets with all functionality removed. If this information is to be used for further runs, it is also necessary to save each of the input sheets using the save buttons on the "Case" sheet.

4. REFERENCES

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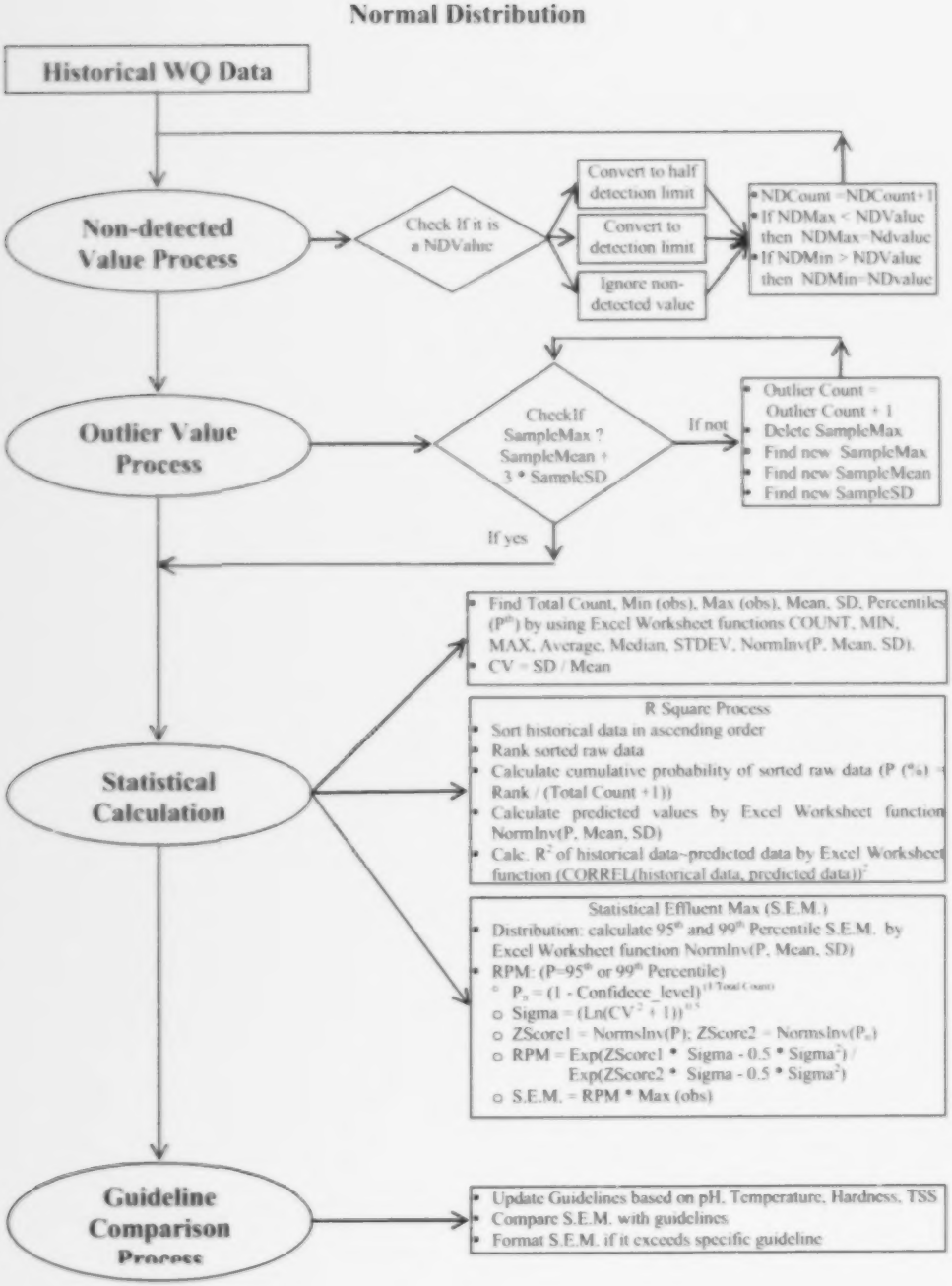
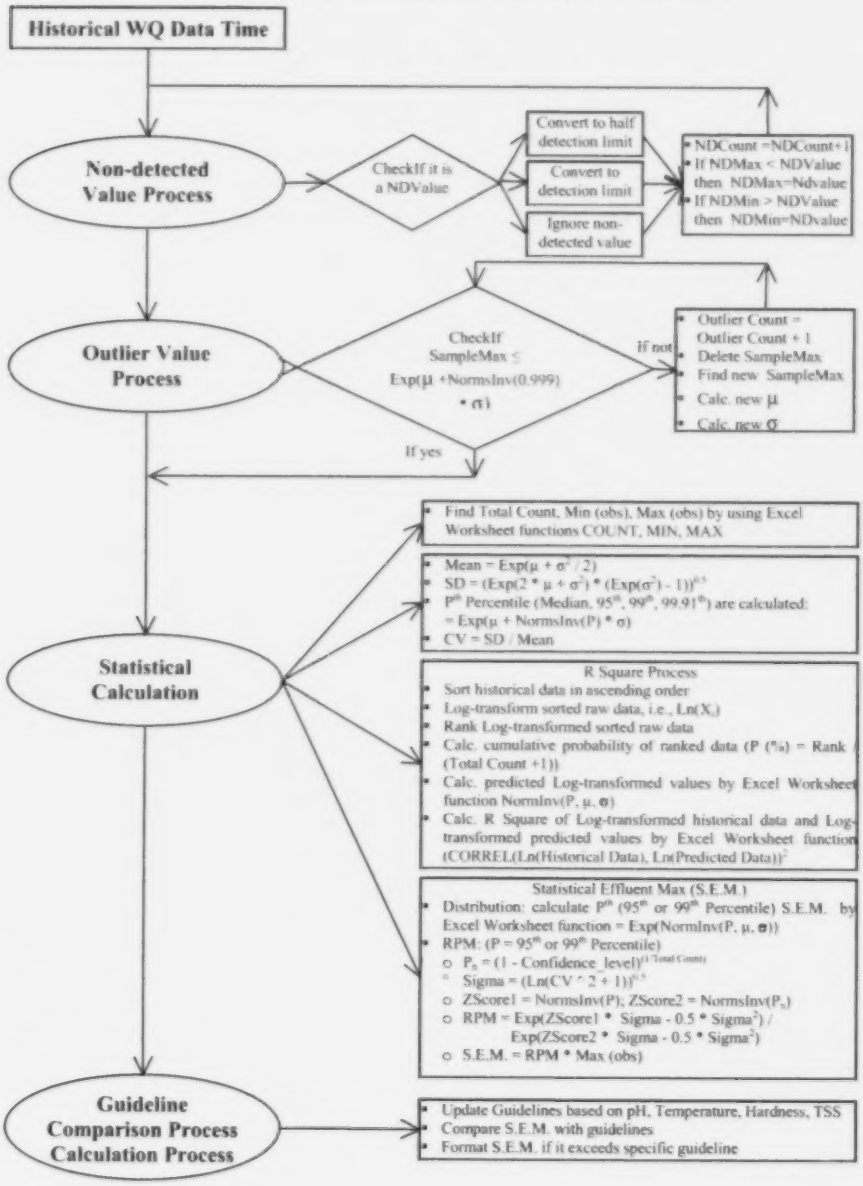
APPENDIX I

EFFLUENT STATISTICS TOOL PROCESSES


Normal Distribution
Historical WQ Data
Non-detected Value Process
Check If it is a NDValue
Convert to half detection limit
Convert to detection limit
Ignore non-detected value
NDCount = NDCount+1
If NDMax < NDValue then NDMax=Ndvalue
If NDMin > NDValue then NDMin=NDvalue
Outlier Value Process
CheckIf SampleMax ? SampleMean + 3 * SampleSD
If not
If yes
Outlier Count = Outlier Count + 1
Delete SampleMax
Find new SampleMax
Find new SampleMean
Find new SampleSD
Statistical Calculation
Find Total Count, Min (obs), Max (obs), Mean, SD, Percentiles (P^th) by using Excel Worksheet functions COUNT, MIN, MAX, Average, Median, STDEV, NormInv(P, Mean, SD).
CV = SD / Mean
R Square Process
Sort historical data in ascending order
Rank sorted raw data
Calculate cumulative probability of sorted raw data (P (%) = Rank / (Total Count +1))
Calculate predicted values by Excel Worksheet function NormInv(P, Mean, SD)
Calc. R2 of historical data~predicted data by Excel Worksheet function (CORREL(historical data, predicted data))2
Statistical Effluent Max (S.E.M.)
Distribution: calculate 95th and 99th Percentile S.E.M. by Excel Worksheet function NormInv(P, Mean, SD)
RPM: (P=95th or 99th Percentile)
Pn = (1 - Confidece_level)^(1/Total Count)
Sigma = (Ln(CV^2 + 1))^0.5
ZScore1 = NormsInv(P); ZScore2 = NormsInv(Pn)
RPM = Exp(ZScore1 * Sigma - 0.5 * Sigma^2) / Exp(ZScore2 * Sigma - 0.5 * Sigma^2)
S.E.M. = RPM * Max (obs)
Guideline Comparison Process
Update Guidelines based on pH, Temperature, Hardness, TSS
Compare S.E.M. with guidelines
Format S.E.M. if it exceeds specific guideline

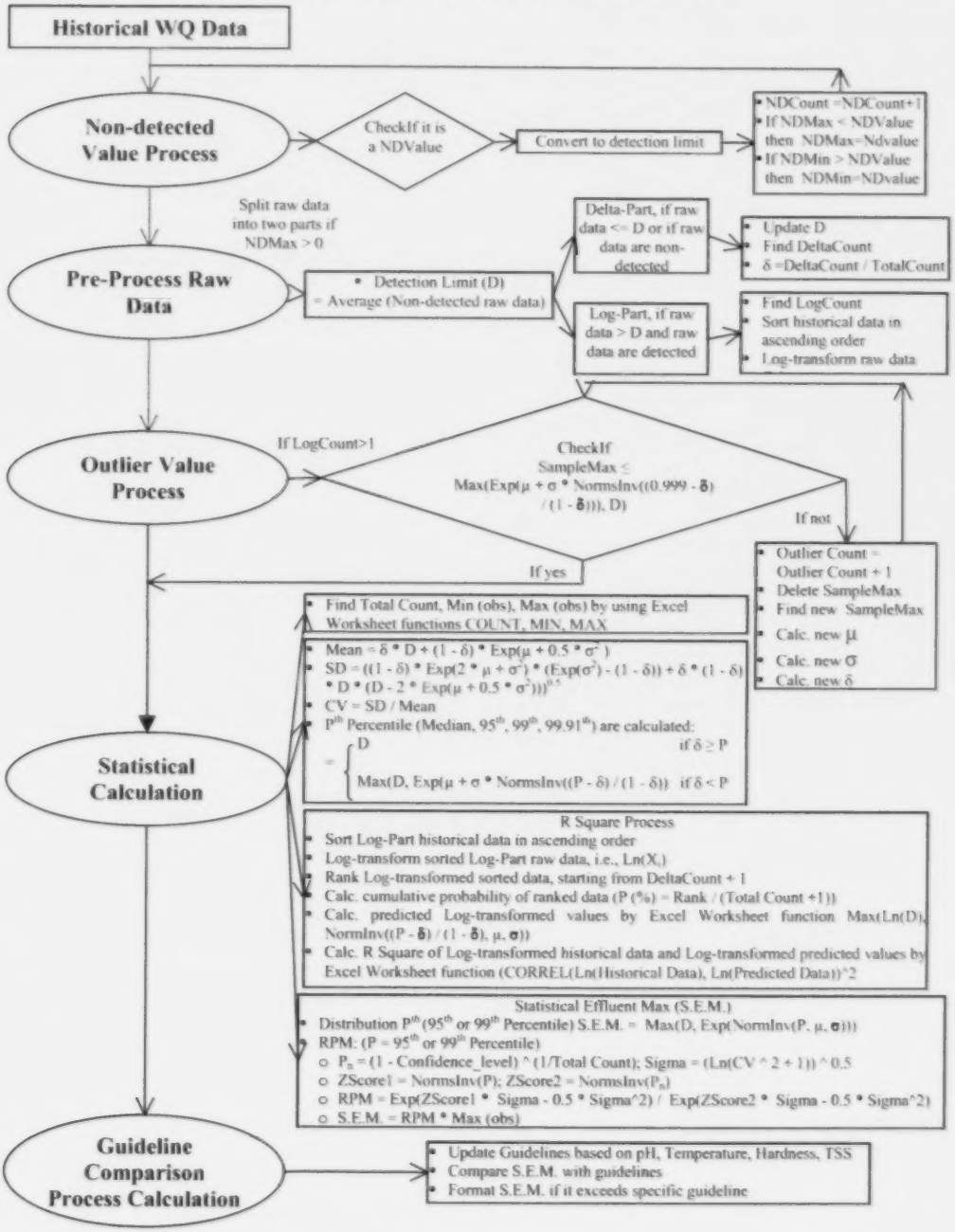
Lognormal Distribution

(assume $Y_i = Ln(X_i)$, the logarithmic transformation of raw WQ data,
$\mu = \sum(Y_i) / K$; $\sigma = (\sum[(Y_i - \mu)^2] / (K-1))^{0.5}$; $i = 1, 2, \ldots, K$)


Historical WQ Data Time
Non-detected Value Process
CheckIf it is a NDValue
Convert to half detection limit
Convert to detection limit
Ignore non-detected value
NDCount =NDCount+1
If NDMax < NDValue then NDMax=Ndvalue
If NDMin > NDValue then NDMin=NDvalue
Outlier Value Process
CheckIf SampleMax ≤ Exp(μ +NormsInv(0.999) * σ)
If not
Outlier Count = Outlier Count + 1
Delete SampleMax
Find new SampleMax
Calc. new μ
Calc. new σ
If yes
Statistical Calculation
Find Total Count, Min (obs), Max (obs) by using Excel Worksheet functions COUNT, MIN, MAX
Mean = Exp(μ + σ² / 2)
SD = (Exp(2 * μ + σ²) * (Exp(σ²) - 1))^0.5
P^th Percentile (Median, 95th, 99th, 99.91th) are calculated: = Exp(μ + NormsInv(P) * σ)
CV = SD / Mean
R Square Process
Sort historical data in ascending order
Log-transform sorted raw data, i.e., Ln(X_i)
Rank Log-transformed sorted raw data
Calc. cumulative probability of ranked data (P (%) = Rank / (Total Count +1))
Calc. predicted Log-transformed values by Excel Worksheet function NormInv(P, μ, σ)
Calc. R Square of Log-transformed historical data and Log-transformed predicted values by Excel Worksheet function (CORREL(Ln(Historical Data), Ln(Predicted Data))²
Statistical Effluent Max (S.E.M.)
Distribution: calculate P^th (95th or 99th Percentile) S.E.M. by Excel Worksheet function = Exp(NormInv(P, μ, σ))
RPM: (P = 95th or 99th Percentile)
P_n = (1 - Confidence_level)^(1/Total Count)
Sigma = (Ln(CV ^ 2 + 1))^0.5
ZScore1 = NormsInv(P); ZScore2 = NormsInv(P_n)
RPM = Exp(ZScore1 * Sigma - 0.5 * Sigma²) / Exp(ZScore2 * Sigma - 0.5 * Sigma²)
S.E.M. = RPM * Max (obs)
Guideline Comparison Process Calculation Process
Update Guidelines based on pH, Temperature, Hardness, TSS
Compare S.E.M. with guidelines
Format S.E.M. if it exceeds specific guideline

Delta-LogNormal Distribution

(assume $Y_i = Ln(X_i)$, the logarithmic transformation of raw WQ data,
$\mu = \sum(Y_i) / K$; $\sigma = (\sum[(Y_i - \mu)^2] / (K - 1))^{0.5}$; $i = 1, 2, \ldots, K$)


Historical WQ Data
Non-detected Value Process
CheckIf it is a NDValue
Convert to detection limit
NDCount =NDCount+1
If NDMax < NDValue then NDMax=Ndvalue
If NDMin > NDValue then NDMin=NDvalue
Split raw data into two parts if NDMax > 0
Pre-Process Raw Data
Detection Limit (D) = Average (Non-detected raw data)
Delta-Part, if raw data <= D or if raw data are non-detected
Update D
Find DeltaCount
δ =DeltaCount / TotalCount
Log-Part, if raw data > D and raw data are detected
Find LogCount
Sort historical data in ascending order
Log-transform raw data
Outlier Value Process
If LogCount>1
CheckIf SampleMax ≤ Max(Exp(μ + σ * NormsInv((0.999 - δ) / (1 - δ))), D)
If not
If yes
Outlier Count = Outlier Count + 1
Delete SampleMax
Find new SampleMax
Calc. new μ
Calc. new σ
Calc. new δ
Statistical Calculation
Find Total Count, Min (obs), Max (obs) by using Excel Worksheet functions COUNT, MIN, MAX
Mean = δ * D + (1 - δ) * Exp(μ + 0.5 * σ²)
SD = ((1 - δ) * Exp(2 * μ + σ²) * (Exp(σ²) - (1 - δ)) + δ * (1 - δ) * D * (D - 2 * Exp(μ + 0.5 * σ²)))^0.5
CV = SD / Mean
Pth Percentile (Median, 95th, 99th, 99.91th) are calculated:
= D if δ ≥ P
= Max(D, Exp(μ + σ * NormsInv((P - δ) / (1 - δ)) if δ < P
R Square Process
Sort Log-Part historical data in ascending order
Log-transform sorted Log-Part raw data, i.e., Ln(Xi)
Rank Log-transformed sorted data, starting from DeltaCount + 1
Calc. cumulative probability of ranked data (P (%) = Rank / (Total Count +1))
Calc. predicted Log-transformed values by Excel Worksheet function Max(Ln(D), NormInv((P - δ) / (1 - δ), μ, σ))
Calc. R Square of Log-transformed historical data and Log-transformed predicted values by Excel Worksheet function (CORREL(Ln(Historical Data), Ln(Predicted Data))^2
Statistical Effluent Max (S.E.M.)
Distribution Pth (95th or 99th Percentile) S.E.M. = Max(D, Exp(NormInv(P, μ, σ)))
RPM: (P = 95th or 99th Percentile)
Pn = (1 - Confidence_level) ^ (1/Total Count); Sigma = (Ln(CV ^ 2 + 1)) ^ 0.5
ZScore1 = NormsInv(P); ZScore2 = NormsInv(Pn)
RPM = Exp(ZScore1 * Sigma - 0.5 * Sigma^2) / Exp(ZScore2 * Sigma - 0.5 * Sigma^2)
S.E.M. = RPM * Max (obs)
Guideline Comparison Process Calculation
Update Guidelines based on pH, Temperature, Hardness, TSS
Compare S.E.M. with guidelines
Format S.E.M. if it exceeds specific guideline

APPENDIX II

MIXING ALGORITHMS

Fractional Mixing

Fractional mixing uses a simple mass-balance equation to calculate what the final substance concentration in the river will be if the effluent is fully mixed within the specified fraction of the river flow, giving the estimated instream concentration. The WLA is calculated and compared to the SEM to check for a reasonable potential to exceed the water quality guideline.

Substance Concentration

The river flow Q_R and fraction F are specified by the user, and the substance concentration is given by:

$$C = \frac{C_{up}Q_{up} + C_{eff}Q_{eff}}{Q_{up} + Q_{eff}} \qquad \text{(AII-1.1)}$$

where C_{up} is the upstream background concentration of the substance of interest, C_{eff} and Q_{eff} are the effluent concentration and flow respectively, and $Q_{up} = Q_R F$.

To calculate the WLA, Eq AII-1.1 is rearranged and C replaced with C_{obj}, the final objective concentration (i.e., the guideline), to give

$$WLA = \frac{C_{obj}\left(Q_{eff} + Q_{up}\right) - C_{up}Q_{up}}{Q_{eff}} \qquad \text{(AII-1.2)}$$

and compared to the SEM to check for a reasonable potential to exceed the guideline.

When the upstream source contribution to the substance concentration is included in the calculation, the Load Screening Tool uses spatial mixing to calculate the upstream concentration.

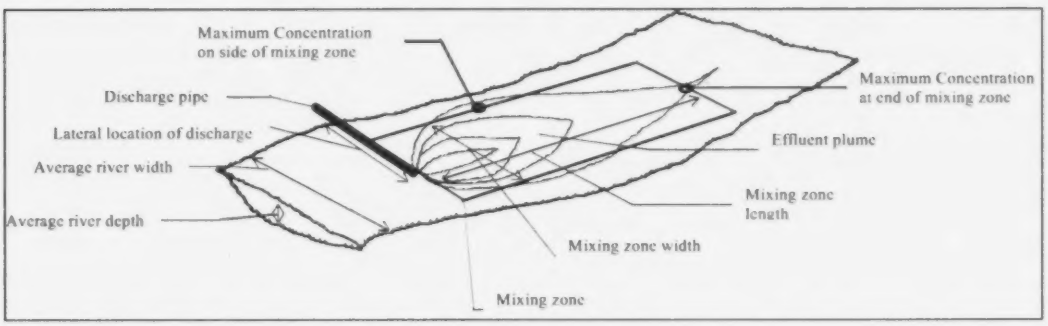
Spatial Mixing

Spatial mixing allows the user to define a mixing zone in the river using the input values in the "MZ & River" sheet. These parameters define the size of the zone and the river characteristics. The tool uses this information to find the point on the edge of the zone having the highest substance concentration. WLA's are then calculated at these points and compared to the SEM to

check for potential exceedances. The mixing zone consists of a user-defined rectangular region of the river extending downstream from the source (Figure 1). The mixing zone is laterally centred around the source location unless this would result in the mixing zone extending out of the river, in which case the location is adjusted to be adjacent to the bank.

For a complete discussion of the theory behind spatial mixing see Mixing in Rivers, Fischer *et al.* (1979).

Figure AII-1
Mixing Zone Schematic



Mixing processes in rivers are mainly governed by advection and dispersion. Advection is the transport by the motion of fluid while dispersion is caused by a velocity gradient. To predict the transport of constituents released to the River, a vertically-averaged, two-dimensional computer simulation model can be developed.

The model is based oGn analytical solutions to river dispersion equations described by Fischer et al. (1979). The model has the capability of handling both point-source releases of surface runoff or effluents and non-point source releases such as groundwater seepage.

The mixing model was based on the following fundamental assumptions:

- The river is relatively shallow so complete vertical mixing occurs rapidly downstream of point-source discharges, hence, a two-dimensional, vertically-averaged model is appropriate.

- The depth of the river is constant and homogeneous across its width, thus, turbulence and dispersion coefficient were set to be constant across the river.
- Mass is conserved in the models by following the standard practice of mathematically reflecting the plume profiles at the river banks which accounts for the finite width of a river.

For a single hypothetical point-source load with negligible flow, the following equation describes concentration at any location downstream of the source (Fischer et al. 1979):

$$C(x,\eta) = C_{BK} + \frac{Me^{-k(x-x_i)/u}}{udW_0\xi\sqrt{\pi}} \sum_{j=-Nr}^{j=Nr} \left\{ \exp\left[-\frac{(\eta - 2j - \eta_0)^2}{\xi^2} \right] + \exp\left[-\frac{(\eta - 2j + \eta_0)^2}{\xi^2} \right] \right\} \quad \textbf{(AII-2.1)}$$

where

$C(x, \eta)$= concentration in the river [mg/L]

x = longitudinal distance downstream from a reference point (*i.e.*, Devon) [m]

x_i = longitudinal distance of source downstream from a reference point (*i.e.*, Devon) [m]

η = the normalized location across the river (normalized by fraction of river flow) [dimensionless]

η_o = the normalized location across the river of the centre of the source (normalized by fraction of river flow) [dimensionless]

ξ = the normalized transverse dispersion parameter, Eq. (AII-2.2) [dimensionless]

C_{BK} = background concentrations in the river [mg/L]

M = load of constituent from the source release [kg/d]

W_0 = river width at the upstream boundary of the modelled reach, Eq. (AII-2.3) [m]

d = depth of the river, Eq. (AII-2.5) [m]

u = velocity of the river Eq. (AII-2.4) [m/s]

j = the j'th reflection

N_r = the number of river bank reflections depends on the rate of lateral mixing across the river and the distance downstream, x, in the calculation; typically N_r=2 will suffice.

k = decay rate of constituent [s^{-1}]

The normalized dispersion parameter (ξ) is described by:

$$\xi = \frac{2d\sqrt{E_t xu}}{Q_{ARO}} \qquad \textbf{(AII-2.2)}$$

where

d = depth of the river [m]

u = velocity of the river [m/s]

E_t = transverse dispersion coefficient [m^2/s]

Leopold-Maddock (1953) relationships (with coefficient a, b, c, d, e, and f) can be used to estimate velocity and depth of the river based on the flow at the upstream boundary (Q_0 in m^3/s):

$$W_0 = aQ_0^b \qquad \textbf{(AII-2.3)}$$

$$u = c\,Q_0^d \qquad \textbf{(AII-2.4)}$$

$$d = e\,Q_0^f \qquad \textbf{(AII-2.5)}$$

Thus, for any given river flow, river depth, velocity as well as dispersion coefficient can be determined, and constituent concentrations at locations downstream of the discharge point can be predicted using the above equations.

Rather that specifying the dispersion coefficient (E_t) a dimensionless dispersion coefficient can be used (ε_t):

$$\varepsilon_t = E_t / du^* \qquad \textbf{(AII-2.6)}$$

The frictional velocity (u^*,m/s), which can be estimated by:

$$u^* = \sqrt{gdS} \qquad \textbf{(AII-2.7)}$$

where

g= gravity (9.81 m/s^2)

S= river slope [dimensionless]

Typically, the range of the dimensionless mixing coefficient is between 0.4 and 0.8.

The model contains adjustments to the basic Fischer equations to accurately approximate the effects of small source flows. Each of the sources is considered to be a line source. The width of the line for source i (w_i [dimensionless]) can be user defined but has a minimum width ($w_{min\ i}$ [dimensionless]) given by:

$$w_{\min i} = Q_{si} / Q(x) \qquad \textbf{(AII-2.8)}$$

where

$Q(x)$ = Flow in the river of the point being modelled [mg/L]

Q_{si} = Flow rate of source i [m^3/s]

Line sources with greater width than the minimum width may be specified, for example, when a release has a multi-port diffuser.

A line-source release can be treated as an infinite number of point sources along a distance across the river equal to the line source's width. An equation for calculating river concentrations downstream of a line source can therefore be derived by integrating the point-source equation over the width of the line source and accounting for the finite width of a river by reflecting the plume at both river bank boundaries. A line source with different flows along the line, such as a

zone of influent groundwater seepage, can be represented as a series of line sources with differing flows. The general equation describing the concentration downstream of several sources is:

$$C(x,\eta) = C_{BK} + \sum_{i=1}^{N_s}\sum_{h=1}^{N_{ti}} \frac{C_{ohi}}{2} e^{-k(x-x_i)/u} \sum_{j=-N_r}^{N_r} \left[\begin{array}{l} \operatorname{erf}\left(\frac{r_{hi}+(\eta-(2j+\eta_{hi}))}{\xi_i}\right)+\operatorname{erf}\left(\frac{r_{hi}-(\eta-(2j+\eta_{hi}))}{\xi_i}\right) \\ +\operatorname{erf}\left(\frac{r_{hi}+(\eta-(2j-\eta_{hi}))}{\xi_i}\right)+\operatorname{erf}\left(\frac{r_{hi}-(\eta-(2j-\eta_{hi}))}{\xi_i}\right) \end{array} \right] \quad \textbf{(AII-2.9)}$$

where:

C_{ohi} = initial concentration of *h'th* section of the *i'th* source, fully vertically mixed over the line source segment river flow fraction. Eq. (AII-2.10) [mg/L]

i = the *i*'th source

h = the *h'th* segment in a series of line sources

N_s = the number of sources upstream of the modelled location

N_{ti} = number of line segments for the *i'th* source

η_{hi} = the normalized location across the river of the centre of the *h'th* source [dimensionless]

ξ_i = the normalized transverse dispersion parameter. Eq. (AII-2.12) [dimensionless]

r_{hi} = half width of the line source segment (w_{hi}) normalized by fraction of river flow, i.e. $r_{hi} = w_{hi}/2$ [dimensionless]

The above line source equation has been normalized by the fraction of river flow (i.e., the lateral distance is represented by the fraction of total river flow). The initial concentration for a line source is calculated by mixing the line source flow with the river flow over the width of the line source:

$$C_{ohi} = \frac{q_{shi} C'_{si}}{2 r_{hi} Q(x)} \quad \textbf{(AII-2.10)}$$

where:

q_{shi} = the line source flow rate [m^3/s] (see next section)

C'_{si} = the line source concentration adjusted to background concentration. Eq (AII-2.11) [mg/L]

C_{si} = the line source concentration which is assumed to be the same for each line source segment, although it need not be [mg/L]

The concentration of the source is adjusted for the background concentration in the river:

$$C'_{si} = C_{si} - C_{BK} \qquad \textbf{(AII-2.11)}$$

The normalized transverse dispersion parameter is given by:

$$\xi_i = \frac{2d\sqrt{E_t xu}}{Q(x) - Q_{si}} \qquad \textbf{(AII-2.12)}$$

where:

ξ_i = the normalized transverse dispersion parameter [dimensionless]

d = depth of the river [m]

u = velocity of the river [m/s]

E_t = transverse dispersion coefficient [m^2/s; Golder 1994a]

The value of d, and u are determined from Q_0 as outlined above in Eq. (AII-2.4) to Eq (AII-2.5).

To account for changes in seepage rate with distance from shore, a series of line sources are used with varying initial concentrations. The initial concentrations are determined by an exponential function and are distributed in such a way that the total seepage mass of constituent is conserved. The seepage rate from the bank to the centre of the river was, therefore, assumed to follow the following form of decay (Shaw and Prepas 1990):

$$q_{si}' = Q_{si} K_1 e^{-k_0 \eta} \qquad \textbf{(AII-2.13)}$$

where:

q_{si}'= line source segment seepage per unit η [dimensionless]

K_f = a scaling constant [dimensionless]

k_Q = exponential decay constant [dimensionless]

Integrating this functional form for the seepage rate over the half width of the river and normalizing by the total seepage, the seepage flow fractions between η_a and η_b can be expressed as:

$$\frac{q_{sab}}{Q_{si}} = \frac{e^{-k_Q \eta_a} - e^{-k_Q \eta_b}}{1 - e^{-0.5 k_Q}} \qquad \textbf{(AII-2.14)}$$

where:

q_{sab} = line source segment seepage between river flow fraction η_a and η_b [m^3/s]

Q_{si} = total seepage to river [m^3/s]

The seepage for each segment can then be expressed in terms of the line source segment centre, η_{hi} and its half width, r_{hi}:

$$\frac{q_{shi}}{Q_{si}} = \frac{e^{-k_Q(\eta_{hi} - r_{hi})} - e^{-k_Q(\eta_{hi} + r_{hi})}}{1 - e^{-0.5 k_Q}} \qquad \textbf{(AII-2.15)}$$

The concentration for an individual release (C_{sp}) that corresponds to a specific target concentration in the river ($C_T(x, \eta)$) can be derived by substituting Eq. (AII-2.10) into equation Eq. (AII-2.9) for that source to give Eq (AII-2.16) and solving for the release concentration to give Eq (AII-2.17).

$$C(x,\eta) = C_{BK} + \sum_{\substack{i=1 \\ i \neq p}}^{N_s} \sum_{h=1}^{N_h} \frac{C_{ssh}}{2} e^{-k(x-x_i)/u} \sum_{j=-N_r}^{N_r} \left[\begin{array}{l} \operatorname{erf}\left(\dfrac{r_i + (\eta - (2j + \eta_h))}{\xi_i} \right) + \operatorname{erf}\left(\dfrac{r_i - (\eta - (2j + \eta_h))}{\xi_i} \right) \\ + \operatorname{erf}\left(\dfrac{r_i + (\eta - (2j - \eta_h))}{\xi_i} \right) + \operatorname{erf}\left(\dfrac{r_i - (\eta - (2j - \eta_h))}{\xi_i} \right) \end{array} \right] \quad \textbf{(AII-2.16)}$$

$$+ (C_{sp} - C_{BK}) \sum_{h=1}^{N_h} \frac{q_{shi}}{2(q_{shi} + 2r_i Q(x))} e^{-k(x-x_i)/u} \sum_{j=-N_r}^{N_r} \left[\begin{array}{l} \operatorname{erf}\left(\dfrac{r_i + (\eta - (2j + \eta_h))}{\xi_i} \right) + \operatorname{erf}\left(\dfrac{r_i - (\eta - (2j + \eta_h))}{\xi_i} \right) \\ + \operatorname{erf}\left(\dfrac{r_i + (\eta - (2j - \eta_h))}{\xi_i} \right) + \operatorname{erf}\left(\dfrac{r_i - (\eta - (2j - \eta_h))}{\xi_i} \right) \end{array} \right]$$

$$C_{sp} = C_{BK} + \frac{C(x,\eta) - C_{BK} - \sum_{\substack{i=1 \\ i \neq p}}^{N_s} \sum_{h=1}^{N_h} \frac{C_{ssh}}{2} e^{-k(x-x_i)/u} \sum_{j=-N_r}^{N_r} \left[\begin{array}{l} \operatorname{erf}\left(\dfrac{r_i + (\eta - (2j + \eta_h))}{\xi_i} \right) + \operatorname{erf}\left(\dfrac{r_i - (\eta - (2j + \eta_h))}{\xi_i} \right) \\ + \operatorname{erf}\left(\dfrac{r_i + (\eta - (2j - \eta_h))}{\xi_i} \right) + \operatorname{erf}\left(\dfrac{r_i - (\eta - (2j - \eta_h))}{\xi_i} \right) \end{array} \right]}{\sum_{h=1}^{N_h} \frac{q_{shi}}{2(q_{shi} + 2r_i Q(x))} e^{-k(x-x_i)/u} \sum_{j=-N_r}^{N_r} \left[\begin{array}{l} \operatorname{erf}\left(\dfrac{r_i + (\eta - (2j + \eta_h))}{\xi_i} \right) + \operatorname{erf}\left(\dfrac{r_i - (\eta - (2j + \eta_h))}{\xi_i} \right) \\ + \operatorname{erf}\left(\dfrac{r_i + (\eta - (2j - \eta_h))}{\xi_i} \right) + \operatorname{erf}\left(\dfrac{r_i - (\eta - (2j - \eta_h))}{\xi_i} \right) \end{array} \right]} \quad \textbf{(AII-2.17)}$$

The WLA for a mixing zone corresponding to source p is the lowest source concentration that result in a target concentration equal to the guideline at any point on the mixing zone boundary.

APPENDIX III

SLOPES FOR ALBERTA RIVERS

Table III-1 Slopes for Alberta Rivers

Basin	River	Location	Latitude	Longitude	Slope (m/m)
Peace	Peace	at Hudson's Hope	56 o 1 ' 39 "	121 o 53 ' 56 "	0.00058
Peace	Peace	near Taylor	56 o 8 ' 9 "	120 o 40 ' 13 "	0.00059
Peace	Peace	at Dunvegan Bridge	55 o 55 ' 0 "	118 o 37 ' 0 "	0.00025
Peace	Peace	at Peace River	56 o 14 ' 41 "	117 o 18 ' 46 "	0.00035
Peace	Peace	near Carcajou	57 o 44 ' 30 "	117 o 1 ' 55 "	0.00094
Peace	Peace	at Fort Vermillion	58 o 23 ' 15 "	115 o 2 ' 5 "	0.00094
Peace	Peace	at Peace Point	59 o 6 ' 50 "	112 o 25 ' 35 "	0.0001
Peace	Smoky	at Prudent's Ranch/Smoky/Watino	55 o 24 ' 56 "	117 o 37 ' 19 "	0.00052
Peace	Wapiti	near Grand Prairie	55 o 4 ' 20 "	118 o 48 ' 10 "	0.00051
Peace	Little Smoky	near Guy	55 o 27 ' 55 "	117 o 9 ' 40 "	0.0011
Peace	Notikewin	at Manning	56 o 55 ' 25 "	117 o 37 ' 35 "	0.0012
Athabasca	Athabasca	at Jasper	52 o 52 ' 35 "	118 o 4 ' 8 "	0.0015
Athabasca	Athabasca	at Entrance/ Hinton	53 o 24 ' 45 "	117 o 35 ' 15 "	0.001
Athabasca	Athabasca	near Whitecourt (near Windfall)	54 o 9 ' 10 "	115 o 43 ' 15 "	0.0012
Athabasca	Athabasca	at Athabasca	54 o 43 ' 20 "	113 o 17 ' 10 "	0.00024
Athabasca	Athabasca	below McMurray	56 o 43 ' 53 "	111 o 24 ' 9 "	0.00011
Athabasca	Athabasca	at Embarras Airport	58 o 12 ' 15 "	111 o 23 ' 32 "	0.00018
Athabasca	Wildhay	near Hinton	53 o 31 ' 24 "	117 o 56 ' 49 "	0.0049
Athabasca	Mcleod	above Embarras River	54 o 28 ' 10 "	116 o 37 ' 45 "	0.00097
Athabasca	Mcleod	near Wolf Ck./Edson	53 o 39 ' 15 "	116 o 16 ' 50 "	0.001
Athabasca	Wolf Creek	at Highway #16	53 o 35 ' 55 "	116 o 16 ' 15 "	0.0012
Athabasca	Freeman	near Fort Assiniboine	54 o 21 ' 53 "	114 o 54 ' 17 "	0.0033
Athabasca	Pembina	below Paddy Creek	53 o 7 ' 55 "	115 o 18 ' 45 "	0.0033
Athabasca	Pembina	near Entwistle	53 o 36 ' 0 "	115 o 0 ' 14 "	0.002
Athabasca	Pembina	at Jarvie	54 o 27 ' 5 "	113 o 59 ' 30 "	0.00022
Athabasca	Lobstick	near Endistle/near Styal	53 o 36 ' 45 "	115 o 6 ' 20 "	0.00072
Athabasca	Paddle	near Rochfort Bridge	53 o 53 ' 50 "	115 o 2 ' 20 "	0.0027
Athabasca	Little Paddle	near Mayerthorpe	53 o 57 ' 40 "	115 o 8 ' 55 "	0.002
Athabasca	Lesser Slave	Slave Lake/at Highway #2	55 o 17 ' 39 "	114 o 35 ' 26 "	0.00022
Athabasca	West Prairie	near High Prairie	55 o 26 ' 0 "	116 o 29 ' 50 "	0.00069